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The Pathophysiology of Boxing Injuries

Loosemore, Michael

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The Pathophysiology of Boxing Injuries

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Michael Paul Loosemore

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Who killed Davey Moore

Why an' what's the reason for?

Bob Dylan 1964

Abstract

This thesis explores the prevalence, nature and pathogenesis of injuries in boxing. Following an introductory chapter and literature review (Chapters 1 and 2 respectively); Chapter 3 examines injuries in the GB boxing squad from 2005 to 2009. There were a total of 66 boxers on the squad during this period 61% were injured, a total of 297 injuries were recorded. The injury rate in competition was at least 460 times higher than in training, and most injuries were new rather than recurrent (246 v 51). The incidence of concussion is comparatively low compared to other studies in amateur boxing (5 in 5 years). Hand and wrist injuries were the most frequent (23.2%).

Chapter 4 describes the nature of hand and wrist injuries in more detail. 'Boxers' knuckle', skiers thumb, Bennett's fracture and carpometacarpal instability were the most frequent hand and wrist injuries and also took the longest time to recover compared to all other hand and wrist injuries that occurred. These injuries occur significantly more frequently in competition than in training (347 injuries per 1,000 hours in competition less than 0.5 per 1000 hours in training).

Chapter 5 describes efforts to identify and validate a means to measure the pressure at each knuckle, given that 'boxers' knuckle' was found to be such a debilitating injury. This does differentiate between the proportion of knuckle impact forces (PKIF) displayed during punching and no punching but displays very poor test-re-test reliability. This method might allow the impact of changes in the hand wraps or the gloves to be measured.

Chapters 6 and 7 deal with head injury in boxing. Head guards were removed from amateur boxers in 2013. The effect of this removal on boxers' health was investigated by reviewing the number of bouts stopped due to blows to the head both with and without head guards (Chapter 6). To improve the quality of this analysis, an examination of video from championships with and without head guards (Chapter 7) was carried out. A significant decrease in observable signs of concussion ($p<0.05$) and a significant increase in cuts ($p<0.001$) was observed when the head guards were removed.

This work will have implications for the protection of boxers' hands and the use of head guards in other contact sports.

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Supporting Material

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6th September 2015 Boxing Injuries, is it all in the Head? Aspetar Doha

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22nd January 2015. RSM. Sports Orthopaedic Conference. Hand injuries' in Boxing

29th October 2014. Talk to plastic surgery unit Swansea re Boxing injuries.

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22nd February 2011 MSc Lecture, Boxing Injuries, Prevention and Management.

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Abbreviations

ABA	Amateur Boxing Association
AIBA	Association Internationale de Boxe Amateur
AMA	American Medical Association
AOB	Amateur Olympic Boxing
BC	Before Christ
BMA	British Medical Association
CCAT	Computerised Cognitive Assessment Tool
CMCJ	Carpometacarpal Joint
CMC	Carpometacarpal
CTBE	Chronic Traumatic Brain Encephalopathy
GB	Great Britain
Kg	Kilogramme
MCP	Metacarpophalangeal
NFL	National Football League
OSC	Observable signs of concussion
Oz	Ounces (1oz=28g, 8oz = 227g, 10oz=284g, 12oz=340g, 16oz=454g, 18oz=510g)
PKIF	Proportion of knuckle impact forces
RSC	Referee Stopped Contest
RSC(H)	Referee Stopped Contest (Head)
RSH(I)	Referee Stopped Contest (Injury)
RSC(O)	Referee Stopped Contest (Out classed)
RTS	Return To Sport
USA	United States of America

1.0 Introduction

Boxing has its origins in pre-history. Carvings dated to around 2000 BC have been discovered in Iran which clearly depict two people boxing. The sport of boxing was well recorded in ancient Greek manuscripts and pottery. Indeed, Hippocrates, the father of medicine, was thought to have written on the subject of boxing injuries around 400BC. Following the Greeks, the Roman's developed boxing into a more violent sport before banning it in 393AD. In the seventeenth and eighteenth century boxing evolved as an English sport with the development of rules and regulations. The Queensbury rules were introduced in 1865 and in 1880 the sport split into two distinct codes, amateur and professional boxing. These two codes have their own distinct rules and regulations.

Despite changes in rules intended to reduce the incidence of injury (e.g. the introduction of a referee; a reduction in the number and length of rounds; and improvements in protective equipment), the incidence of injury remained high. Patterns of injury differ between professional and amateur boxing. Given the significantly greater participation in Amateur Olympic Boxing (AOB) an estimated 10 million participants are registered worldwide (over 6 million in the USA alone) there is a need to establish accurate objective data on the incidence and etiology of injury, and mitigating interventions, in this discipline. There are relatively few peer reviewed data, perhaps because research efforts have been limited. A full medical literature search (PubMed, 7th of October 2015) for the term 'Boxing injuries' produced 771 papers, and that for 'Rugby injuries' some 4284 (despite its shorter history and fewer participants). Much of this research in boxing is restricted to issues relating to head injury. As a result, relatively little is known about what injuries are common in amateur boxing, whether they occur in training or competition, what region of the body is affected, or how long it takes injured boxers to return to their sport. There is a dearth of literature examining the impact of equipment, gloves and head guards on injury rates in boxing.

Despite such a sparse evidence base, some in the medical profession actively campaign for the sport to be banned. In 1993, the British Medical Association (BMA) (1) published a book containing the medical evidence which supported their assertion that boxing should be banned . In it, they state:

'In light of the apparently growing body of evidence of injury associated with boxing including: death, acute brain damage, chronic brain damage, ocular damage especially the problem of retinal detachment, chondral damage to the ears and deforming injuries to the nose, the British Medical Association (BMA) has passed a series of resolutions at its annual representative meetings calling for boxing to be made illegal' (Table 1.1).

Date	Motion passed at annual representatives meeting of the BMA
1982	That in the view of the proven ocular and brain damage resulting from professional boxing; the Association should campaign for its abolition.
1987	That in view of the continuing serious ill effects on the health of boxers this meeting requests the BMA to pursue the Government with renewed vigor until there is a ban on boxing, and until such time as this is achieved, believes that television coverage should include a statement of the damage which may result from boxing.
1992	That the forthcoming publication of the revised report on boxing be welcomed and that this meeting calls for a total ban on amateur and professional boxing in the UK. This meeting believes that as the next stage of our campaign against boxing we should seek to ban children below the age of consent from boxing.
1995	This annual representatives meeting believes that all forms of boxing should be banned.
1998	In the light of the recent decision to grant a female boxer a professional license this Association reaffirms its opposition to amateur and professional boxing on the grounds of the hazards it poses to both sexes.

Table 1.1 Timeline of Motions Passed At the BMA Annual Representatives Meetings

The BMA's opposition to boxing is stated to be:

'not based on moral considerations, but upon medical evidence that reveals the risk not only of acute injury but also of chronic damage in those who survive a career in boxing.'

If decisions made by medical associations are underpinned by weak evidence, so too might be those made by the sport's governing bodies. Despite the opposition to boxing from many medical associations across the globe, the Association Internationale de Boxe Amateur (AIBA), the international governing body for AOB, removed head guards from male AOB boxers in 2013. This was partly justified by the suggestion that the number of stoppages from blows to the head increased when head guards were introduced in 1984. However, many other rule changes happened around the same time, so proof of cause and effect was lacking. Nonetheless, when head guards were removed, the number of stoppages due to head blows was significantly reduced by 20% (2).

Likewise, data relating to hand injury are sparse: Only 13 articles were identified as including hand data within a boxing injury review (3-15). Only one review of hand injuries in boxing was identified (16).

As identified in the subsequent review of the literature the level of hand injuries appears to be much higher in Amateur Olympic Boxing (AOB) boxers than in professional boxers in competition. This is surprising as professional boxers will fight for more rounds (up to 12 rounds compared to 3 in AOB) and wear lighter gloves (8oz (227g)) for professionals compared to 10oz (284g) or 12oz (340 g) in AOB. It is clear that a more detailed examination of hand injuries in AOB is important so that prevention strategies' can be implemented and properly evaluated.

In this thesis, I thus attempt to present new data, particularly in those fields where empirical evidence is currently sparse. Experimental chapters examine the pathophysiology of boxing injuries focusing on injuries to the hand and wrist, and the effect of the removal of head guards on head injuries among male AOB boxers in 2013.

2.0 Literature Review

The following literature review begins with an historical overview of the sport to place the thesis in context. This is then followed by a detailed examination of the published work pertaining to boxing injuries. A key focus of the literature review is on injuries acquired in Amateur Open Boxing (AOB) and more specifically injuries to the wrist, hand and head.

2.1 An Historical Overview of the Sport of Boxing

The following section provides an historic overview of the sport of boxing and the evolution of rules and regulations leading to the current structure in the sport.

2.1.1 Pre-History

It is hypothesised that humans have evolved with the hand proportions we have today because of the evolutionary advantage attributed to humans' ability to fight with the superior weapon of the clenched hands or fists. Of note, humans (*Homo sapiens*) are the only member of the great ape family that are able to make a fist.
The use of the fist as a weapon and the ability to form a fist as an evolutionary advantage was suggested by Morgan and Carrier (17) who noted that humans are the only member of the great apes where the proportion of the finger length to the palm length is short enough to make a fist. This club like structure is further strengthened by buttressing from the thenar and hypothenar eminence. This allows striking with much greater force through the axis of the metacarpals, especially the second and third metacarpal, and is enhanced by no angular movement at the second and third carpometacarpal joint. Of note Morgan and Carrier (17) demonstrated that the force generated by a fist is much greater than the force generated by the open hand.

2.1.2 Ancient History

Boxing or fighting with clenched fists is one of the most ancient of all recorded sports, a logical sequelae of the evolutionary hypothesis put forward by Morgan and Carrier (17). Sumerian relief carvings show depictions of boxing discovered in Iran thought to be from around 2000-3000 BC (18). (Figure 2.1) There are written texts from the same period showing that fighting athletes were on the royal staff with special privileges including owning their own house (19).

Figure 2.1 Terracotta Plaque of Wrestlers and Boxers.3000-2340 B.C.

A terracotta relief also from Iran (20) dated to 2000BC shows the unmistakable depiction of a boxing match (Figure 2.2), showing that the form of the sport has changed little in the last 4000 years.

Figure 2.2 Terracotta Relief of Two Mesopotamian Boxers, c. 2000 B.C. from Eshnunna, (Modern-day Tell Asram, Iraq).

In India about 1000BC fighting without weapons was part of the training of the Ksatreya (a warrior caste of ancient India). The Ksatreya normally fought with weapons from horseback or chariot; however if they were unseated they were taught to fight on foot without weapons using only their fists. The Ksatreya developed a form of boxing skill which they called Vajramukhti, a name meaning "thunderbolt closed hands."

Figure 2.3 Yamantaka, Fear-Striking Vajra, Lord of Death (Tibetan: Gshin-rje-gshed), multiheaded, holding vajra, rope, dagger, riding a water buffalo, statue of a guardian, enormous strength, Tibetan Esoteric Buddhism, Art Institute, Chicago, Illinois, USA.

The word Vajramukhti was derived from the vajra maces of traditional warfare (Figure 2.3), the fists being compared to the solid head of the mace or possibly because the mace was held in a clenched fist. Vajramukti (boxing) was also practiced in peacetime as a means of keeping fit. This involved technical movement patterns of attack and defence (21).

The practice of boxing is recorded in ancient manuscripts from Shang Dynasty (1766-1122 BC), the first documented era of ancient China. In the Buddhist Shaolin temple in Dengfeng county, Zhengzhou, Henan province, there is a fresco showing Indian monks teaching Chinese students the art of bare-handed fighting. Extending the arm to strike with the hands was one of the martial arts known as 'Da'. The inscription on the fresco states: 'Tenjiku Naranokaku' which means: "the fighting techniques to train the body from India". The monks became teachers and spread this skill all over China. This form of martial art later became known as Shaolin boxing (22).

There are records of the use of the fist in fighting competitions by at least one group of Native South Americans, the Yanomamo (23). It would appear that all over the world, and as far back as recorded history goes, boxing or fighting with clenched fists has evolved.

2.1.3 The Ancient Greeks

The Ancient Greeks held the first Olympic Games in 776BC. Boxing was established as an Olympic sport at the 23rd Olympiad in 688BC (24) and continued as an Olympic sport until the end of the Ancient Olympics. The greatest knowledge of boxing in ancient times comes from the writings, statues, and poetry of the Ancient Greeks (Figure 2.4). The Ancient Greeks considered boxing as an integral part of health (25). The Gods and several of the earliest heroes are described as distinguished boxers, such as Apollo, Heracles, Tgdeus and Polydeuces. Apollo was the guardian of the sport as mentioned in the Homeric hymn:

'Wherever (in Delos) the Ionians gather with their long tunics to honour you, along with their children and modest wives, with every event they please you with boxing joy and songs' (26).

As the following passage from Homer's Iliad illustrates boxing in ancient Greece is comparable to modern boxing and clearly recognisable as the same sport. The boxers are fighting for a prize (in this case a female Donkey), there is some 'trash talking' before the bout "*I will smash his skin apart and break his bones".* The boxer prepares for the fight by wearing a protective belt and wrapping his hands. The challenger is knocked out and beaten, but retains the admiration of the victor (27).

“Sons of Atreus, and all you other strong-greaved Achaians, we invite two men, the best among you, to contend for these prizes with their hands up for the blows of boxing.
He whom Apollo grants to outlast the other, and all the Achaians witness it, let him lead away the hard-working jenny to his own shelter.
The beaten man shall take away the two-handled goblet.”

He spoke, and a man huge and powerful, well skilled in boxing, rose up among them; the son of Panopeus, Epeios.
He laid his hand on the hard-working jenny, and spoke out:
“Let the man come up who will carry off the two-handled goblet.
I say no other of the Achaians will beat me at boxing and lead off the jenny.
I claim I am the champion.
Is it not enough that I fall short in battle?
Since it could not be ever, that a man could be a master in every endeavour.
For I tell you this straight out, and it will be a thing accomplished.
I will smash his skin apart and break his bones on each other.
Let those who care for him wait nearby in a huddle about him to carry him out, after my fists have beaten him under.”

So he spoke, and all of them stayed stricken to silence.
Alone Euryalos stood up to face him, a godlike man, son of lord Mekisteus of the seed of Talaos; of him who came once to Thebes and the tomb of Oidipous after his downfall, and there in boxing defeated all the Kadmeians.
The spear-famed son of Tydeus was his second, and talked to him in encouragement, and much desired the victory for him.
First he pulled on the boxing belt about his waist, and then gave him the thongs carefully cut from the hide of a ranging ox.
The two men, girt up, strode into the midst of the circle and faced each other, and put up their ponderous hands at the same time and closed, so that their heavy arms were crossing each other, and there was a fierce grinding of teeth, the sweat began to run everywhere from their bodies.
Great Epeios came in, and hit him as he peered out from his guard, on the cheek, and he could no longer keep his feet, but where he stood the glorious limbs gave.

As in the water roughened by the north wind a fish jumps in the weed of the beach-break, then the dark water closes above him, so Euryalos left the ground from the blow, but great-hearted Epeios took him in his arms and set him upright, and his true companions stood about him, and led him out of the circle, feet dragging as he spat up the thick blood and rolled his head over on one side. He was dizzy when they brought him back and set him among them. But they themselves went and carried off the two-handled goblet.

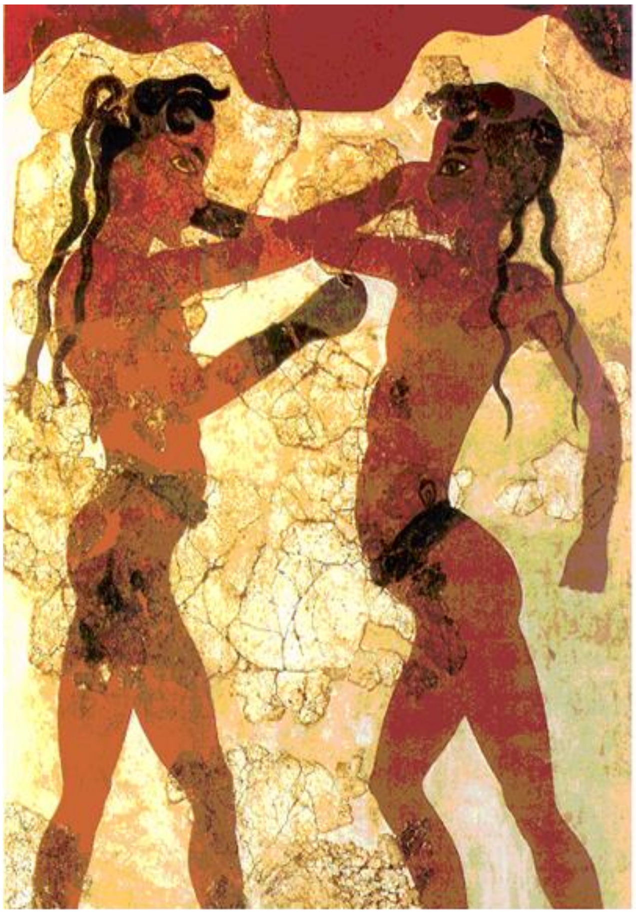

Figure 2.4 Boys Boxing (Bronze Age) from Akrotiri, Santorini, Greece1600 BC.

In ancient Greece it was considered a citizen's duty to remain fit so the gymnasium was at the centre of Greek society and boxing was at the centre of the gymnasium. It is unsurprising that, with hundreds of years of boxing experience, the Ancient Greeks had a broad knowledge of boxing injuries.

2.1.3.1 The Ancient Greeks Knowledge of Boxing Injuries.

The iconic bronze statue now known as 'A Boxer at Rest' (Figure 2.5) was excavated from Quirinal Hill in Rome in 1885. It is thought to be an accurate portrayal of a boxer from the Hellenistic period (323-331 BC) (28). This bronze has been given many attributes. It seems to have been based on earlier depictions of

Hercules by Lysippos, so the boxer is given God-like status; Greek legend suggests that many of the Greek gods boxed, including Zeus the father of the Gods. The boxer is seen as a hero embodying strength and courage; others see the boxer as an older athlete, clearly beaten in a fight which has just finished. He is still wearing his hand wraps and the protector (*kynodèsme*) that he would have fought in the wounds sustained on his face and ears are obvious and still bleeding (Figure 2.6 and 2.7). It is speculated that he is sitting contemplating the end of his career.

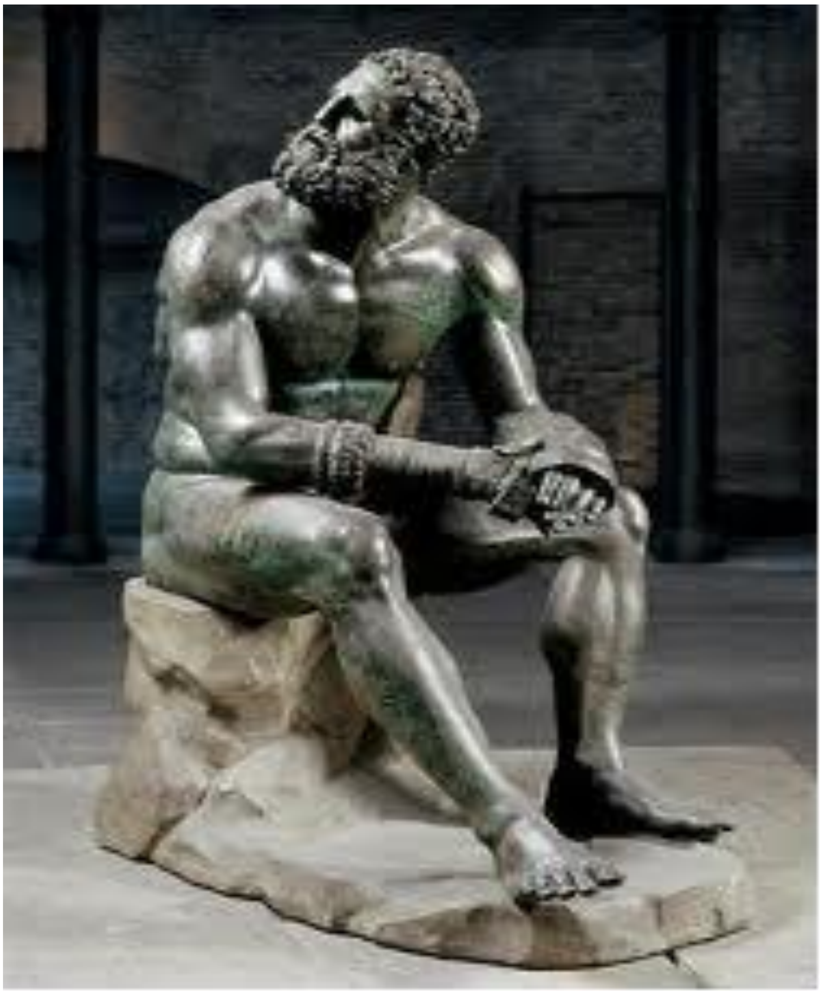

Figure 2.5 Boxer at Rest, Greek, Hellenistic period, late 4th–2nd Century B.C.

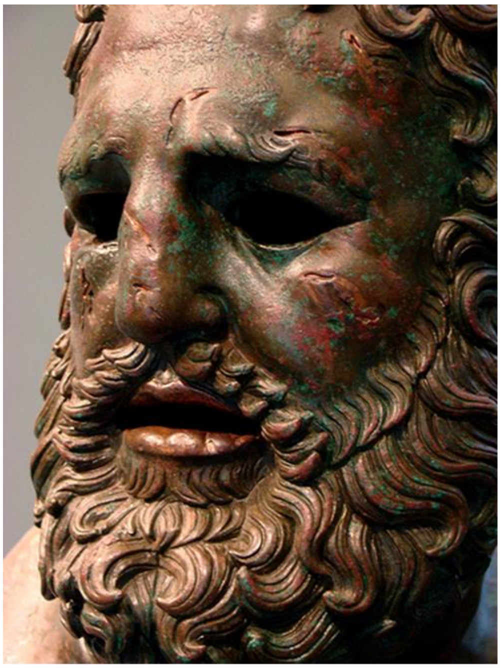

Figure 2.6 Detail from Boxer at Rest, Demonstrating Injuries to the Face.

An alternative hypothesis about the statue is that the boxer is indeed badly injured, with all the boxing injuries that we teach doctors learning about boxing injuries today. The boxer has sustained a cut across his broken nose (an open fracture), a cut over the trochlea nerve, the supra orbital nerve, infra orbital nerve, and the vermillion border of the lip (Figure 2.6). He also has bleeding between the skin and cartilage of his pinna (cauliflower ear) which is also cut (Figure 2.7).

Figure 2.7 Detail from Boxer at Rest. Bleeding Between the Skin and Cartilage of His Pinna (Cauliflower Ear)

Interestingly his injured face has all of these cuts and none are repeated. It is very unlikely that a boxer would sustain all these injuries in a fight, and if he was beaten so badly then he would almost certainly have more than one of the different cuts illustrated. As this is such an accurate representation of the possible injuries sustained in boxing it may have been a teaching aid to show doctors in training where the common cuts and injuries are. Indeed modern pictures of where all the important cuts are located would be a mirror image of the 'Boxer at Rest' face. Figure 2.8 shows the location of cuts where the doctor at ringside should stop the fight.

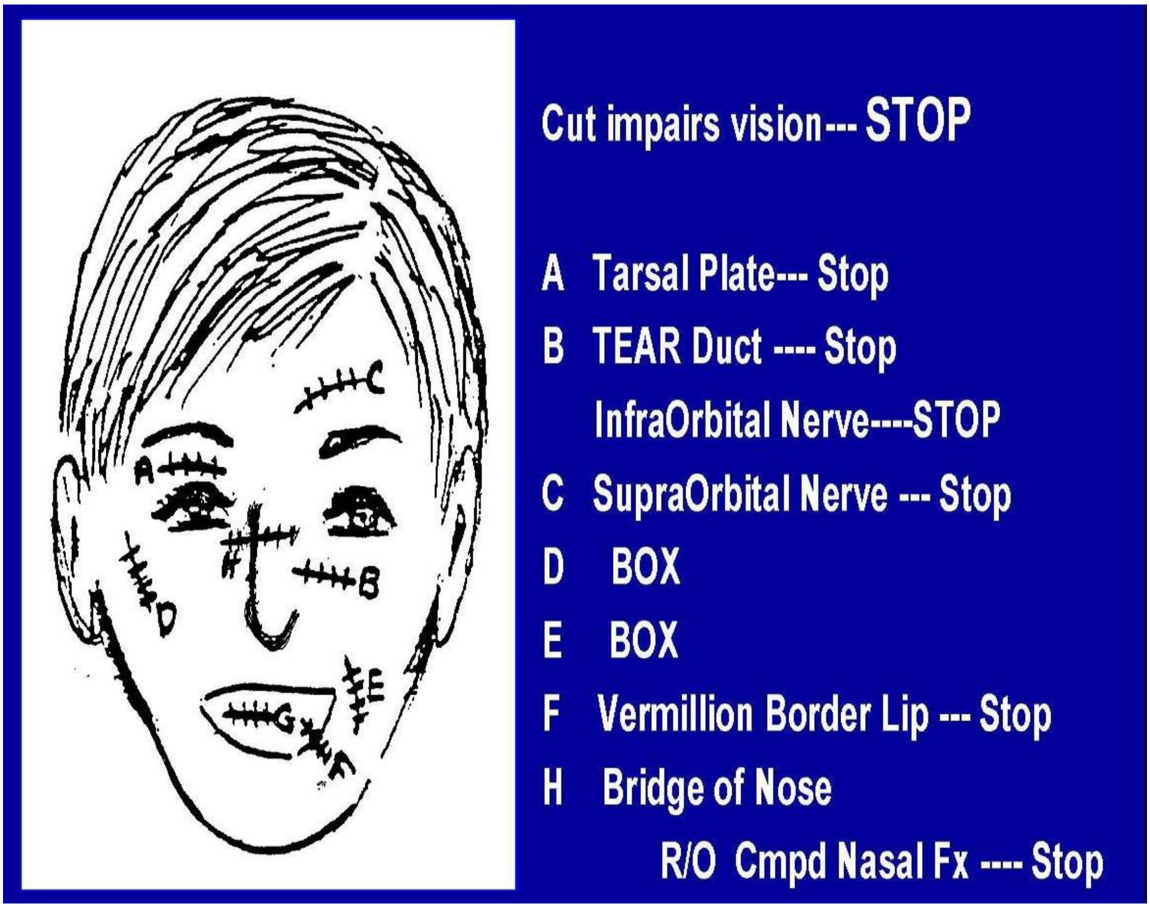

Figure 2.8 Modern Teaching Slide Illustrating Cuts Which Require a Boxer to be Stopped.

As boxing had been practiced in Greece for hundreds of years when this bronze was cast and that Greek doctors were trained in the injuries caused by boxing, it is not surprising that it was worth the time and expense to produce such an accurate training aid. Indeed Hippocrates, considered the father of medicine (29), is thought to have written only 4 of the 70 books of medical text attributed to him. In one text he describes a fatal injury to a wrestler who died four days after his opponent landed on him (19). These texts concentrated on injuries to the nose, face and jaw. Injuries associated with boxing and wrestling rather than warfare. This is not surprising as Hippocrates teacher was Herodocus, referred to by Plato in Republic as an athletic trainer (30).

2.1.3.2 Equipment to Prevent Injuries

Hundreds of years of experience of boxing injuries led to various forms of protection for athletes. To protect the hands the boxers wrapped them in soft leather thongs (cestertus). Over several hundred years the cestertus developed from the soft thongs in Ancient Greece until in Roman times the hand wrap acquired iron studs (Figure 2.9).

Figure 2.9 The Development of the Boxing Hand Wrap from Greek to Roman.

During training some texts report the wearing of extra padding on the boxers hands (spheres) to protect the opponent as well as the wearer. There is also evidence of head guards being worn (Figure 2.10) possibly to prevent cauliflower ears, a term used by Plato as a disparaging description of Spartans who were known for their prowess at boxing (30).

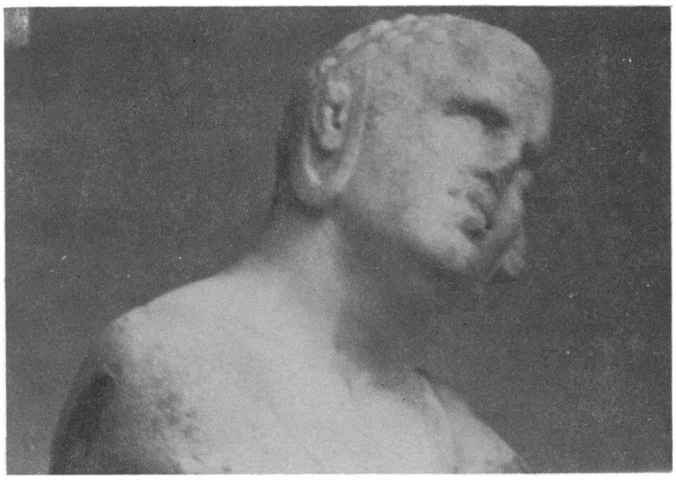

Figure 2.10 Boxer Wearing Ear Guards (4th cent. BC) Met. Mus. Art

2.1.4 Roman Boxing

Roman gladiatorial boxing, as opposed to the high minded boxing practiced by the Ancient Greeks in the gymnasia and the Olympic games, was a product of Roman culture and part of the gladiatorial circus. With boxers from all parts of the Roman Empire performing for the circus crowd (Figure 2.11). The soft leather wraps around the fists of Greek boxers transformed with the Romans need for spectacle into hard leather gloves (cerstus) and eventually with iron spiked adornments (Figure 2.9); this would often lead to a lethal end to the contest (31). It would appear that even in ancient times there was a difference between Olympic boxing, as practiced by the Gods and Greek citizens to achieve inner perfection and enlightenment, and professional boxing as practiced in the gladiatorial arena which was a bloody, and sometimes lethal, entertainment for the Roman circus crowd.

Figure 2.11 Roman Terracotta Figures of African Boxers.

Greek boxing came to an end in 393AD when the Christian Emperor Theodsius banned the Olympic Games, and in 500AD boxing was banned throughout the Roman Empire altogether by Theodoric the Great, because boxing disfigured the face it was considered an insult to God, as man was made in God's image (18).

2.1.5 Boxing in Medieval England

After the Romans left Britain in 504AD there is little recorded about boxing as a sport. Time was dedicated to war and survival, although it is probable boxing in one form or another did continue.

Sport was seen as preparation for war. Between 1000 and 1500 knights would practice skills on horseback such as jousting, whilst the peasants would practice archery, boxing, water tilting and wrestling (32). The main concern of the authorities appears to have been the reduction in the practice of archery and the disorder caused by ball games, especially football. The law appears to have singled out ball games while combat sports and boxing do not appear to have been a concern to the authorities at the time (33).

Henry the VIII was a keen promotor of sport. With the kingdom in a more stable position with no major wars either foreign or civil and the church breaking away from the Roman Catholic Church in Rome, a more liberal attitude was taken toward sport in general. This allowed sports including boxing to become more organised and prosper.

2.1.6 Boxing in England from the Seventeenth Century (The English Sport)

With the restoration of the monarchy in 1660 the Puritan era was over and sport and other previously discouraged entertainments could flourish.

In 1681 The Protestant Mercury printed what is thought to be the earliest written report of a boxing match in England.

> *"Yesterday a match of boxing was performed before His Grace the Duke of Albemarle between the Dukes footman and a butcher. The latter won the prize, as he hath done many times before, being accounted though a little man, the best at the exercise in England" (34)*.

This short report suggests several things. The Butcher was considered the finest boxer in England, so an organised form of boxing must have been conducted for some time before this fight took place to reach this conclusion. There was patronage from the nobility, so the sport must have gained acceptance into general society as a spectacle and an entertainment.

2.1.6.1 James Figg and John (Jack) Broughton

Many people attribute the birth of modern boxing to James Figg from Thame in Oxfordshire. He would take on all comers and was considered the champion of England in the second decade of the eighteenth century. It was not just boxing that he was famed for; he was also talented in the use of cudgels and was a fine sword fencer. He was also a great self-publicist and entrepreneur describing himself as the "Oxonian Professor" (35).

With the increasing amount of industrialisation and poverty in the cities of early eighteenth century England the levels of disorder increased. With no police force to maintain order and protect the public, it is unsurprising that the Regency gentleman attended Figgs' Academy to learn self-defence.

Figg opened a boxing academy in Tottenham Court Road in London in 1719. He engaged with the gentry and the zeitgeist of the time, by emphasising the connection with the ancient Greeks, describing his boxing emporium as Figgs' Amphitheatre. He relocated to the Adam & Eve pub in Oxford Street where he fought and promoted contests. The association of pubs with boxing clubs continues to this day. Figg attracted the rich and famous, some of his hand bills were drawn by his friend William Hogarth (Figure 2.12) and he also claimed Jonathan Swift and Robert Walpole as students in his academy (36).

John (Jack) Broughton is known as the father of English boxing. He was a pupil of James Figg. Jack Broughton became boxing champion of England in 1738.

Figure 2.12 James Figg, Trade Card (circa, 1725), Willliam Hogarth. N.B The British Museum claim the image reprinted here was actually created by another printmaker and engraver, Anna Maria Ireland.

2.1.6.2 The Fancy

Around 1660 it became fashionable for young noblemen to be sent on ‘The Grand Tour’. The Grand Tour was associated with a standard itinerary with visits to Paris, Venice, Florence, and above all Rome. It served as an educational rite of passage. Boxing re-emerged in England in the Seventeenth century simultaneously with the re-discovery of the classical world (Herculaneum was discovered in 1709) and the concept of leisure. The group of the social elite, educated in Ancient Greek and familiar with the works of Plato and Homer followed the entertainment of bare knuckle boxing in the boxing booths at travelling fares and racecourses. They were prominent at many prize fights and were known as ‘The Fancy’.

This elite group is epitomised by the romantic poet Lord Byron who was a keen boxer and an advocate of boxing. Like horse racing, boxing brought together the opposite ends of society in one sport. Lord Byron keen to learn how to box employed a prize fighter John Jackson to teach him. When chided by his friends for keeping company with pugilists he insisted that Jackson’s manners were ‘infinitely superior to those of the fellows of the college I meet at the high table’ (37).

Lord Byron's appreciation for Jackson are illustrated in the following lines in 'Hints from Horace':

And men unpracticed in exchanging knocks
Must go to Jackson if they dare to box.

Boxing became strongly associated with the British establishment and was considered an English sport. Boxing showed courage and toughness as opposed to fencing which was associated with the foppish French (38). In England, fighting with the fists was considered noble whereas fighting with a weapon was considered cowardly. The resolution of disputes with a boxing contest was also far less lethal than a duel with swords. The high standing that boxing enjoyed in the eighteenth century is illustrated by this passage from *Popular Recreations in English Society, 1700–1850 (39)*:

Everyone who sees them preparing for a fight surrounds them, not in order to separate them, but on the contrary to enjoy the fight, for it is a great sport to the lookers-on, and they judge the blows and also help to enforce the rules in use for this mode of warfare. The spectators sometime get so interested that they lay bets on the combatants and form a big circle around them. The two champions shake hands before commencing and then attack each other courageously with their fists and sometimes also with their heads, which they use like rams.

2.1.6.3 Death, Disfigurement and Rules

Whilst boxing was popular the dangers of the sport were becoming apparent. Prize fighting had few rules, resulting in a high incidence of serious injury and death in the ring. In February 1741, Broughton fought the inexperienced George Stephenson of Hull for the bare-knuckle championship of England. The fight took place in a fairground booth located near Figg's old academy. Jack Broughton knocked out George Stephenson in 35 minutes. Stephenson died from injuries he sustained in the fight. This affected Broughton badly and as a result, the 'Broughton Rules' to govern boxing were devised (Appendix 1).

The eighteenth-century English poet, Paul Whitehead, described the fight's tragic end in a poem entitled 'The Gymnasiad or Boxing Match'(40):

Now droop'd the Youth [Stevenson], yet urging all his might,
With feeble Arm still vindicates the Fight
Till on the Part where heaved the panting breath,
A fatal blow impress'd the Seal of Death.

In 1736 the Northampton Mercury reported the deaths that had occurred in the City of London in the week between the 13th and 20th of July that year: from convulsions-144, smallpox-83, dropsy-20 and killed by boxing-2.

In June 1830 the Scottish champion Alexander McKay fought an Irishman Simon Byrne, after 46 rounds McKay was rendered unconscious; he did not recover and died the following day. He was buried in Hanslope Churchyard, Milton Keynes (Figure 2.13) (41).

Strong and athletic was my frame,
Far from my native land I came,
And bravely fought with Simon Byrne,
Alas, but never to return.
Stranger take warning from my fate,
Lest you should rue your case too late,
If you have ever fought before,
Determine now to fight no more.

Figure 2.13 McKay's Headstone. Hanslope Churchyard, Milton Keynes

Subsequently in 1833 Simon Byrne fought James 'Deaf Un' Burke. Byrne was knocked out in the 96th round of their English Championship fight, he never recovered and died 3 days later. The public revulsion was such that Burke had to move to America to continue his boxing career.

In spite of the attempt to regulate boxing in 1743 with the introduction of 'Broughtons rules' there was still public concern and some distaste around the practice of prize fighting. In September 1845 the Illustrated London News said:

'For years the practice of pugilism has been one revolting to mankind, degrading to all the honourable and honest feelings of human nature . . . A recent exhibition - with an illusion to which we will not pollute our page - has placed The Ring in a position to damage the character of any man who shall hereafter be known to endure a prize fight.'

In 1839, the London Prize Ring rules were introduced which superseded 'Broughton's rules’. Later revised in 1853, they stipulated the following:

- Fights occur in a 24-foot-square ring surrounded by ropes.
- If a fighter was knocked down, he must rise within 30 seconds of his own power to be allowed to continue.
- Biting, head-butting and hitting below the belt were declared fouls.

In a reaction to the threat of the criminalisation of prize fighting a new set of rules were drawn up by Lord Queensberry, these rules made the wearing of gloves mandatory for the first time. Prizefighting gained some respectability with the introduction of these safety based rules first published in 1865 (42). (Appendix 2)

As well as making the wearing of gloves mandatory the Queensberry rules also introduced the concept of three minute rounds with a one minute break between rounds. Another rule which was introduced at the time was the 10 second count; which allowed the referee to stop the contest, if the stricken boxer was unable to recover (defend themselves) within 10 seconds. Previous to the introduction of the Queensbury rules the boxers had three nominated seconds, one of the seconds duties would be, following a knock down, to enter the ring drag the boxer to his corner to revive him for the next round (43). The seconds would also act as guarantors of the purse their boxer died in the ring. In modern boxing the seconds are usually the coach and 2 assistants.

The Queensbury rules, however, did not place a limit on the number of rounds. It was assumed that the fight would end when one boxer was unable to continue, was counted out, or gave up.

The first amateur boxing contest, i.e. boxing for sport rather than money, was recorded in 1860 followed later by the formation of the Amateur Boxing Association in London in 1880 (44). The first Amateur Boxing Association Championship was held at St James Hall, Piccadilly, London on the 18th of April 1881 (45).

The Queensbury rules were improved with the addition of awarding points to boxers for defined, scoring blows, the premise being that both boxers would be standing at the end of the contest. This allowed a winner to be pronounced after a limited number of rounds and introducing the concept of winning on points rather than winning because the opponent was unable to continue either due to submission or unconsciousness. The concept of points scoring a fight was taken up by the professional promoters, as it meant that the number of rounds could be limited (rounds were initially limited to 45). This allowed a venue to be booked, as the maximum time of the fight would be known.

2.1.7 Development of Modern Olympic Boxing

Boxing was introduced into the modern Olympics at the second modern Olympiad in 1900, using the new amateur rules and apart from being absent from the 1912 Stockholm games (boxing was illegal in Sweden at this time), has been present in every other Olympics since.

The requirement for a pre-contest medical examination (medicals) for amateur boxers was introduced in 1906 (45). In 1950 medical cards for every amateur boxer were introduced. All boxers carried a medical card on which all the bouts they have taken part in were recorded with the outcome, any head injury sustained, and mandatory suspensions imposed. This ensured that any injuries were known at subsequent bouts, and also to ensure that the boxers' experience was known, so that the boxer can be fairly and safely matched to an opponent. An amateur boxer could not compete without this card. All boxers get a full medical every year, until they retire at the age of forty. In addition to medicals, boxers are medically examined by a doctor immediately prior to every contest. There is always a doctor at ring side who is trained and equipped for resuscitation. Where the doctor is not trained or equipped for resuscitation there are always suitably trained paramedics present (46). With some minor changes the medical card remains the same today.

In the next section the literature on injuries in boxing is examined. The level of evidence supporting such claims in the literature is reviewed.

2.2 Boxing Injuries

The following section presents a systematic review of the literature examining boxing injuries by anatomical location. Eligible studies for the review were observational studies of either professional or amateur boxing athletes that reported the proportion of injury by anatomical location as a result of either boxing competition or training. The inclusion and exclusion criteria are provided in Table 2.2

Inclusion	**Exclusion**
Observational study design Population of boxing athletes Recording injuries by anatomical location Any publication date	Non-English language article Duplicates Injuries occurring not in competition or training

Table 2.2 Inclusion and Exclusion Criteria

The PubMed peer-reviewed database was systematically searched from the first available record. The search terms were (1) boxing AND (2) injury OR injuries, subject to a date limit of 30 September 2014 and a requirement for studies to be performed in humans. No other key terms, Boolean operators or limits were used. In addition to this database search, the reference lists of obtained full-texts were examined to identify studies that may have been missed by the database searches. Following the initial database searches, duplicates were removed manually to form an initial summary list. The abstracts of articles on this list were screened and potentially relevant articles identified. The full texts of these studies were obtained. Contact was not made with any of the authors in order to identify other potentially relevant articles because all but 3 of the included studies date back more than 10 years. Many date back to the 1980s and one dated back to the

1950s. Therefore, most texts did not have sufficient information to contact the authors.

On the basis of reviewing the full texts of all those articles obtained and assessing them for eligibility in line with the inclusion and exclusion criteria (Table 2.2), non-eligible articles were excluded, leaving only those to be included in the systematic review.

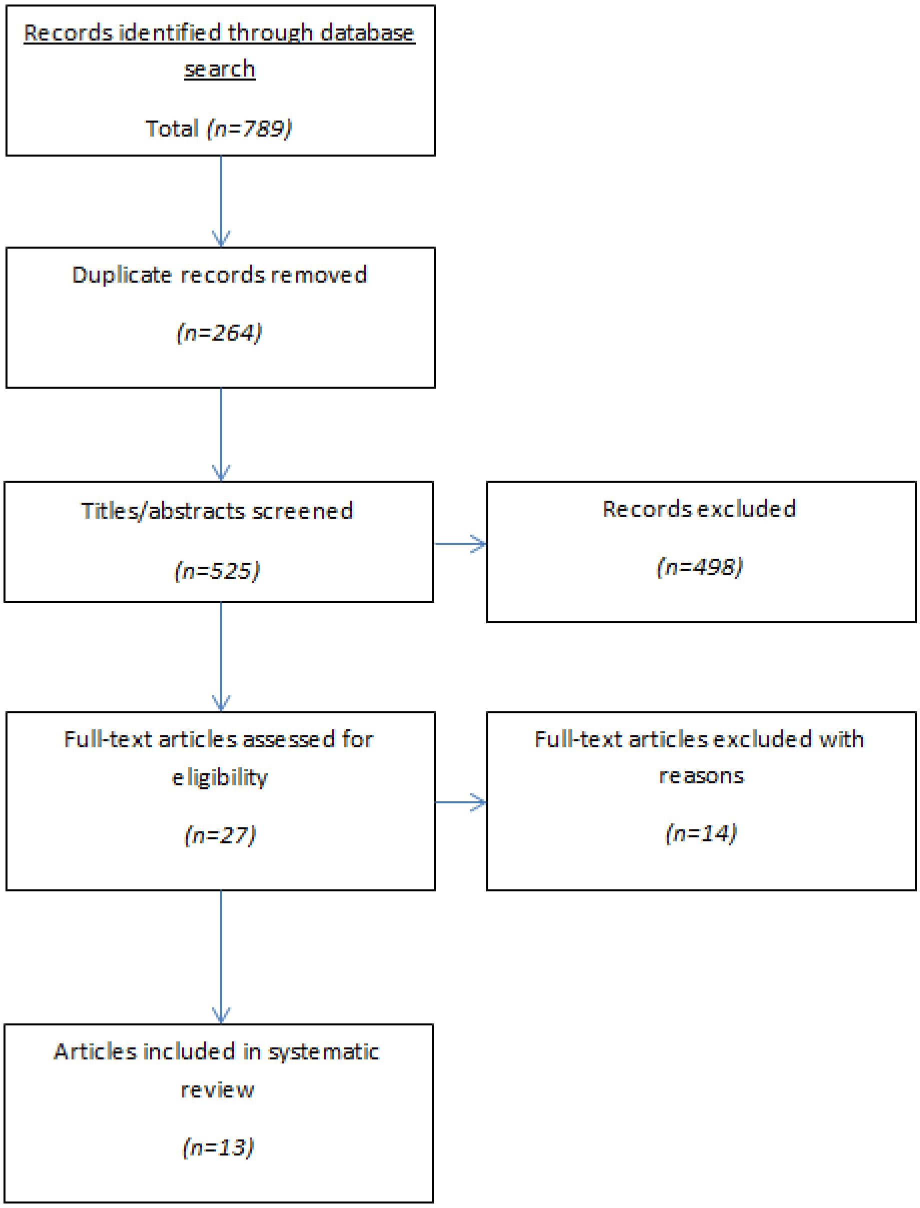

Figure 2.14 Flow Chart of Systematic Review

After finalising the studies for incorporation into the review, data were extracted from each study by the author. The data extracted were tabulated in rows on a spreadsheet using Microsoft Excel (Microsoft Corp., Redmond, WA), with each row containing a single trial. The data extracted included the title, main author, study design, duration, training status of the population (amateur or professional), type of activity (training, competition, or both), number of subjects, total number of injuries, number of injuries in major anatomical region (head, upper extremity, lower extremity, trunk and other), specific anatomical location within the head region (face and scalp, nose, eye and eyebrow, mouth, jaw, ear, throat/neck, cerebral/neural /concussion, and non-specified), specific anatomical location within the upper extremity region (hand, shoulder, thumb, fingers, wrist, elbow, forearm, upper arm, clavicle), specific anatomical location within the lower extremity (knee, ankle, thigh, lower limb, foot, hip or groin, toes, non-specified), specific anatomical location within the trunk and other region (lumbo-pelvic, chest and ribs, neck, thorax, abdomen, other spine, non-specified or other).

Risk of bias of individual studies was not assessed as no statistical information was extracted from the individual studies that would permit any such analysis to be performed. Additionally, no assessment of study quality was performed. Owing to the extremely wide range of the dates over which the included studies were published (1959 - 2015), it quickly became apparent during the course of the review that the information necessary for an assessment of study quality was not reported routinely in each paper.

The outcomes considered in this systematic review were (1) the proportion of injuries in each major region, and (2) the proportion of injuries in each anatomical location within each major region. These outcomes were calculated as percentages using the data extracted from each study and reported as ranges. The only other analyses that were performed were the means and medians of the individual injury proportions by major region and by individual location.

2.2.1 Results

2.2.1.1 Search Results

After following the search process outlined, 13 articles were finally identified as being eligible for review (3-15). Two of these articles Porter and O'Brien (14), Zazryn et al. 2006 (15), were prospective cohort trials and the remainder were cross-sectional studies and therefore retrospective by design.

2.2.1.2 Injuries by Region

Overall, the most common injury region in boxing appeared to be the head (range: 27 – 96% of all reported injuries), accounting for the greatest proportion of injuries by region (Table 2.3).These are not brain injuries alone but include all other injuries to the head including cuts to the face. The range of results was large, with some studies reporting almost exclusively head injuries and other studies reporting relatively few (10).

The Timm study also includes boxers in training where injury rates will be lower (3). This high level of variability was reflected in the proportions of injuries in the other regions, as follows: upper extremity range: 2 – 46%, lower extremity range: 0 – 24%; and trunk and other range = 0 – 16%.

The variability in lower limb and trunk injuries can be explained by the low number of these injuries and the variance in the detail of the injury data recorded.

Study	Trial type	Training status	Training or competition	Period	Total n in study	Head	Upper extremity	Lower extremity	Trunk & other
McCown 1959	R	Professional	Competition	7 years	1,089	96%	4%	0%	-
Jordan 1988	R	Professional	Competition	2 years	376	93%	2%	-	4%
Zazryn 2003	R	Professional	Competition	16 years	107	90%	7%	-	3%
Bledsoe 2005	R	Professional	Competition	1.5 years	191	74%	22%	2%	2%
Zazryn.2009	R	Professional	Competition	8.5 years	214	86%	8%	1%	5%
Oelman 1983	R	Amateur (army)	Training	12 years	437	68%	14%	5%	14%
Estwanik 1984	R	Amateur	Competition	8 days	52	48%	44%	4%	4%
Welch 1986	R	Amateur (army)	Training	2 years	294	48%	46%	4%	2%
Jordan 1990	R	Amateur	Competition	10 years	447	27%	33%	24%	16%
Timm 1993	R	Amateur	Both	15 years	1,219	28%	36%	22%	14%
Porter 1996	P	Amateur	Competition	5 months	64	72%	23%	5%	-
Bianco 2005	R	Amateur	Competition	1.75 years	20	75%	20%	5%	-
Zazryn 2006	P	Both	Both	1 year	21	71%	24%	-	5%
Total / range					**4,531**	**27-96%**	**2 – 46%**	**0 - 24%**	**0 - 16%**

Table 2.3 Studies Reporting Number of Boxing Injuries by Anatomical Location

R=Retrospective P=Prospective

2.2.1.2.1 Head Injury

The most common injury location in boxing within the head region was the face/scalp, accounting for a large range (range: 0 – 96%) of injuries by anatomical location (Table 2.4). This large variation as discussed previously is partly due to the difference between professional and AOB. It can also be explained by the variability in definitions used in different papers: Welch and colleagues (8) did not define face and scalp separately but did report nose and jaw injury, whilst McCown (12) categorised 96% of all the injuries to the head as face and scalp injuries and reported no concussion.

Concussions comprised a mean of 25% of head injury over all studies. Given that head injury accounts for 67% of all boxing injuries, concussions when reported comprised approximately 17% of all injuries in boxing. Notwithstanding the apparent possibility that many concussions may have gone unreported in the literature, this is markedly lower than the overall proportion of head injury. Again the definition of concussion was variable in the papers reviewed. This varied between reporting by the ringside physician (47), being added by the author when a knock out (KO) was reported in the bout (5) to a KO not being considered an injury and so not reported at all (6).

2.2.1.2.2 Upper Extremity Injury

The most common injury location in boxing within the major category of the upper extremity was the hand, accounting for the largest proportion (range: 7 – 100%) of injuries by anatomical location (Table 2.5).

Since the hand-wrist complex is the most common upper extremity boxing injury location, it is useful to assess the proportion of overall injuries that are located at the hand-wrist complex. Injuries to the hand-wrist complex comprised a mean of 74% of upper extremity injury. Given that injuries to the hand-wrist complex accounts for 22% of all upper extremity injuries, injuries to the hand-wrist complex comprised approximately 16% of all injuries in boxing.

2.2.1.2.3 Lower Extremity Injury

The most common injury location in boxing within the major category of the lower extremity was the ankle, (range: 0 – 100%) of injuries by anatomical location (Table 2.6). The total number of injuries in this major category was very low in comparison with the head and the upper extremity and therefore it is difficult to draw meaningful conclusions based on these data.

2.2.1.2.4 Trunk Injury

The most common injury location in boxing within the major category of the trunk was reported to be the chest and ribs, accounting for most (range: 0 – 100%) of injuries by anatomical location in this category (Table 2.7). The total number of injuries in this major category was very low in comparison with the head and the upper extremity and therefore it is difficult to draw meaningful inferences from these data.

Study	Trial type	Status	**Injuries (n)**	**Face & scalp**	**Nose**	**Eye & eyebrow**	**Mouth**	**Jaw**	**Ear**	**Neck**	**Concu-ssion**	**Non-specifi**
McCown 1959	R	Pro	1,049	96%	2%	2%	-	0%	-	-	-	-
Jordan 1988	R	Pro	351	19%	1%	4%	-	1%	0%	-	75%	-
Zazryn 2003	R	Pro	96	26%	-	51%	-	2%	-	-	21%	-
Bledsoe 2005	R	Pro	142	68%	7%	19%	1%	2%	2%	-	-	-
Zazryn 2009	R	Pro	184	12%	4%	63%	3%	2%	2%	1%	14%	-
Oelman 1983	R	Am (army)	296	34%	-	-	-	-	-	-	62%	4%
Estwanik 1984	R	Am	25	56%	12%	12%	8%	-	12%	-	-	-
Welch 1986	R	Am (army)	142	-	80%	-	-	4%	-	-	15%	-
Jordan 1990	R	Am	121	7%	28%	19%	11%	6%	4%	-	26%	-
Timm 1993	R	Am	344	42%	21%	13%	9%	8%	6%	1%	-	-
Porter 1996	P	Am	46	9%	11%	7%	-	-	2%	-	72%	-
Bianco 2005	R	Am	15	93%	-	7%	-	-	-	-	-	-
Zazryn 2006	P	Both	15	-	27%	27%	-	-	-	-	47%	-
Total / range			**2,823**	**7 – 96%**	**0-80%**	**0 - 63%**	**0–11%**	**0 – 8%**	**0-12%**	**0–1%**	**0 – 75%**	**0 – 4%**

Table 2.4 Injuries to the Region of the Head. R=Retrospective P=Prospective. Pro=Professional Am=Amateur.

Study	Trial type	Status	Injuries n	Hand	Shoulder	Thumb	Fingers	Wrist	Elbow	Fore-arm	Upper-arm	Clavicle
McCown 1959	R	Pro	39	82%	10%	-	8%	-	-	-	-	-
Jordan 1988	R	Pro	9	89%	11%	-	-	-	-	-	-	-
Zazryn 2003	R	Pro	8	88%	-	-	-	-	-	-	13%	-
Bledsoe 2005	R	Pro	42	79%	14%	-	-	-	7%	-	-	-
Zazryn 2009	R	Pro	17	87%	6%	-	-	-	-	-	6%	-
Oelman 1983	R	Am (army)	59	47%	-	-	-	-	-	8%	2%	42%
Estwanik 1984	R	Am	23	57%	-	30%	-	9%	-	-	-	4%
Welch 1986	R	Am (army)	134	7%	49%	10%	5%	19%	10%	-	-	-
Jordan 1990	R	Am	147	24%	22%	12%	18%	9%	11%	2%	3%	-
Timm 1993	R	Am	441	24%	20%	14%	13%	10%	10%	4%	4%	2%
Porter 1996	P	Am	15	53%	-	13%	-	20%	13%	-	-	-
Bianco 2005	R	Am	4	100%	-	-	-	-	-	-	-	-
Zazryn 2006	P	Both	5	20%	20%	-	-	20%	20%	-	20%	-
Total / range			**943**	**7–100%**	**0-49%**	**0-30%**	**0 – 18%**	**0-20%**	**0–20%**	**0–8%**	**0–20%**	**0–42%**

Table 2.5 Boxing Upper Extremity Injuries by Location R=Retrospective P=Prospective. Pro=Professional Am=Amateur.

Study	Trial type	Status	Injuries n	Knee	Ankle	Thigh	Lower limb	Foot	Hip or groin	Toes	Non-specified
McCown 1959	R	Pro	1	-	100%	-	-	-	-	-	-
Jordan 1988	R	Pro	-	-	-	-	-	-	-	-	-
Zazryn 2003	R	Pro	-	-	-	-	-	-	-	-	-
Bledsoe 2005	R	Pro	3	-	67%	-	-	33%	-	-	-
Zazryn 2009	R	Pro	3	-	64%	-	36%	-	-	-	-
Oelman 1983	R	Am (army)	21	48%	-	-	14%	-	-	-	38%
Estwanik 1984	R	Am	2	50%	50%	-	-	-	-	-	-
Welch 1986	R	Am (army)	12	25%	67%	8%	-	-	-	-	-
Jordan 1990	R	Am	107	34%	25%	6%	18%	11%	7%	-	-
Timm 1993	R	Am	267	29%	25%	15%	11%	9%	6%	4%	-
Porter 1996	P	Am	3	33%	33%	-	33%	-	-	-	-
Bianco 2005	R	Am	1	-	-	100%	-	-	-	-	-
Zazryn 2006	P	Both	-	-	-	-	-	-	-	-	-
Total / range			**420**	**0–50%**	**0–100%**	**0–100%**	**0–36%**	**0-33%**	**0–7%**	**0–4%**	**0–38%**

Table 2.6 Boxing Lower Extremity Injuries by Location. R=Retrospective P=Prospective. Pro=Professional Am=Amateur.

Study	Trial type	Status	Number	Lumbo-pelvic	Chest and ribs	Neck	Thorax	Abdomen	Other spine	Non-specified
McCown 1959	R	Pro	-	-	-	-	-	-	-	-
Jordan 1988	R	Pro	16	-	19%	-	-	44%	-	38%
Zazryn 2003	R	Pro	3	-	-	-	-	33%	-	67%
Bledsoe 2005	R	Pro	4	-	75%	-	-	25%	-	-
Zazryn 2009	R	Pro	10	-	19%	-	-	19%	-	62%
Oelman 1983	R	Am (army)	61	-	5%	-	-	-	28%	67%
Estwanik 1984	R	Am	2	50%	50%	-	-	-	-	-
Welch 1986	R	Am (army)	6	-	17%	67%	-	17%	-	-
Jordan 1990	R	Am	72	-	24%	-	-	1%	75%	-
Timm 1993	R	Am	167	29%	28%	25%	13%	6%	-	-
Porter 1996	P	Am	-	-	-	-	-	-	-	-
Bianco 2005	R	Am	-	-	-	-	-	-	-	-
Zazryn 2006	P	Both	1	-	100%	-	-	-	-	-
Total / range			**342**	**0–50%**	**0–100%**	**0–67%**	**0–13%**	**0–44%**	**0–75%**	**0–67%**

Table 2.7 Boxing Trunk and Other Injuries by Location R=Retrospective P=Prospective. Pro=Professional Am=Amateur.

2.2.2. Discussion

The purpose of this systematic review was to assess the proportion of injuries that occur in each anatomical location during either boxing competition or training, as reported in observational studies performed in both professional and amateur boxers.

This review supports the traditional assumptions about boxing that associate the sport with head injury. Most (range: 28 – 96%) injuries appeared to occur in the head region, with the majority of reports displaying greater proportions of head injury compared with the upper extremity (range = 2 – 46%), lower extremity (range = 0 – 24%) and trunk/other regions (0 – 16%). Nevertheless, although injury to the head region appears to account for the largest proportion of boxing injuries, concussion accounts for a smaller percentage because of the high incidence of facial lacerations.

2.2.2.1 Head Injury

There was considerable variability in the proportion of injury to the head region (range: 28 – 96%) and in the components of the head region. In respect of the proportion of head injury comprised of facial lacerations, the difference in reported results was very large (range = 7 – 96%), with some studies reporting no face/scalp injuries (8), others reporting a very small number of face/scalp injuries, and others reporting almost all head injuries in this subcategory

The studies with high facial injuries and head injuries are in professional boxing in competition. Professional bouts last from 4 to 12, 3 minute rounds with no protection to prevent cuts and an increased risk of head injury as the refereeing style is different from AOB in that professional boxers are allowed to take more blows to the head before the referee will intervene. In amateur boxing the head and face are protected from cuts in competition by the head guards, the bouts are of shorter duration, 3x3 minute rounds. In amateur boxing the referee will step in at the first sign of distress from a boxer and stop the fight.

This variability seems to be partly attributable to absolute number of face/scalp injuries incurred. Porter and O'Brien (14) noted that the type of headgear worn (if any) may affect the number of facial lacerations that occur. It is therefore noteworthy that the study resulting in the single greatest proportion of facial lacerations reported the earliest period of boxing (1952 – 1958) in which headgear was not worn (12).

Additionally, the variability may be partly attributable to the lack of consistency regarding the how face/scalp injuries are classified in relation to the other subcategories of nose, eye and eyebrow, mouth, jaw, ear, throat and neck. Jordan and Campbell (9) noted that attending physicians at boxing matches are less likely to record facial lacerations on injury forms unless they require sutures, which does indicate a lack of consistency.

In respect of the proportion of head injury comprised of concussions, the difference in reported results was similarly very large (range = 0 – 75%). There is some evidence to suggest that there may be some variability between studies in the way in which cerebral (concussion) injury is defined and consequently recorded, which may be partly responsible for these differences. This may be because the databases that are used in retrospective studies of boxing injury were not originally designed to be used for this purpose. Bledsoe and colleagues (6) presented data retrospectively regarding professional boxing matches in the state of Nevada from the Nevada State Athletic Commission. These data recorded no concussions in the injury reports, despite reporting that 51% of fights ended in either a technical knockout or knockout. The same authors commented that injury significant enough to lead to knockout is doubtless evidence of damage and therefore that their data likely underestimate the incidence of concussion quite significantly. Other studies have explicitly noted that their definition of concussion was where a knockout occurred (9) or is particularly conservative (8) in that it records any sign of vertigo or nausea as cerebral injury.

2.2.2.2 Upper Extremity Injury

There was considerable variability in the proportion of injury to the head region and in the components of the upper extremity region (range: 2 – 46%). To be noted there was a great deal of variability in the proportion of upper extremity injuries occurring in the hand (range: 7 – 100%).

Upper extremity variability again can be explained in the differences between amateur and professional boxing. In professional boxing the glove size is smaller 8oz (227g) compared to 10oz (284g) in AOB (during the period covered by these studies) however hand injuries are far less common in professional boxing. In professional boxing any amount of hand wrap and tape is allowed, the only restriction being the ability to fit the wrapped hand into the boxing glove. In AOB, at the time of these studies, hand wraps were limited to 2.5m of crepe bandage per hand.

While this variation is explained partly by the difference in the hand protection allowed in professional and AOB, as discussed previously, it also reflects the variation in the definitions used by authors.

Bianco and colleagues (7) do not sub divide their injury definition so all appear as hand injuries. Some of this variability could be caused by differences in the classifications of anatomical locations around the hand, such as the fingers, thumb, and wrist. Indeed, the range is somewhat reduced when considering the hand-wrist complex (i.e. hand, finger, thumb, and wrist subcategories) and in this case the hand-wrist complex accounts for the large majority of upper extremity injury, with a mean 74% (range: 40 – 100%) of injuries in the upper extremity. Nevertheless, a considerable amount of between-study variability remained that was not explained, this could have arisen due to various factors: training status, (full time or part time): the boxing federation rules which may have changed during the duration of the period analysed.

Noble (16) conducted the only epidemiological study that has so far been carried out purely in relation to boxing hand injuries. They included case studies and case series. One hundred consecutive boxing injuries to the hand in 86 boxers were assessed. These boxers presented either post-match or in the office of the South African Boxing Board of Control. Noble (16) reported that 23% of hand injuries involved the ulnar collateral ligament of the metacarpophalangeal (MCP) joint of the thumb ("skier's thumb"), 10% involved carpometacarpal (CMC) joint injuries of the thumb ("Bennett's fracture and dislocation"), 12% involved damage to the second to fifth MCP joint soft tissues (also called "boxer's knuckle"), 12% involved inflammation of the second to fifth CMC joints, 12% involved subluxation of one or more metacarpal bases, and 8% involved metacarpal fractures of the second to fifth metacarpals, with the majority of these occurring in the fifth metacarpal ("boxer's fracture). Noble's findings are similar to those reported in the studies included in this analysis. Skier's thumb was reported as representing a high proportion (30%) of upper extremity injuries by Estwanik et al (11) and (13%) reported by Porter (14). Boxer's knuckle was also reported as representing a high proportion of upper extremity injuries (34%) by Porter (14). Boxer's fracture and other metacarpal fractures were reported as being a high proportion (9%) of upper extremity injuries by Estwanik et al (11), and (13%) by Porter (14) and (47%) by Oelman (13).

These findings are similar to those reported in a clinical report performed by McDougall (48), which noted that common boxing hand injuries included boxer's knuckle, boxer's fracture and Bennett's fracture, and skier's thumb. In cases of boxer's knuckle, two case series indicate that this particular injury may affect the third metacarpal most often, followed by the fifth metacarpal (49, 50). However, McCown's (12) findings indicate that it may be the second and third metacarpals that are most commonly affected.

2.2.2.3 Lower Extremity and Trunk Injury

There was considerable variability in the proportion of injury to the lower extremity (range = 0 – 24%) and trunk/other regions (range = 0 – 16%). However, the number of injuries reported in the lower extremity and trunk/other regions were very low and the ability to analyse these data are therefore very limited.

It is relevant to note that Porter and O'Brien (14) observed that the lower-body injuries incurred in their trial were similar to overuse injuries typically found in long-distance runners. They speculated that such injuries may relate to the nature of boxing training, which often involves long-distance running, rather than actual boxing competition. Indeed, Porter and O'Brien (14) did note a large difference in the proportion of lower extremity injury between training and competition (41% vs. 5%), which supports this observation.

2.2.3 Limitations

There were several key limitations of this review. Firstly, the review was limited insofar as no quantitative analysis was performed of the reported results. Owing to the extremely wide range of the dates over which the included studies were published (1959 - 2015), it quickly became apparent during the course of the review that the information necessary for an assessment of study quality was not reported routinely in each paper.

Secondly, it was limited by the relative paucity of high-quality, relevant studies with large sample sizes. Only two of the included trials were prospective cohort trials. These trials are more likely to produce an accurate result as there are fewer sources of bias and confounding factors compared to all the other studies that were cross sectional studies. Unfortunately the sample size in the prospective cohort trials was comparatively small. Thirdly, the review was limited by the very large ranges observed in the reported proportions of injury by anatomical location. This large variance makes prediction of an accurate figure very difficult introducing bias into these findings.

Thirdly, this study was limited because only one data base was searched.

This heterogeneity between studies appears to have arisen for a variety of reasons, including the apparently very different definitions of certain key injuries, including concussion, which was defined in some studies as being equal to a knockout but not in others. A related limitation of this study in this respect was that this heterogeneity was not assessed formally by the use of statistical analysis. Therefore, the underlying factors that may have been responsible for the differences in reported outcomes were not definitively identified. It was also limited as only one person reviewed the literature, so it is possible that some key information may have been missed. This would have been improved if more than one person had extracted the data.

2.2.4 Conclusions

Boxing has historically most commonly been associated with head injury. Indeed, a summary of the literature supports this view, with most (range: 28 – 96%) injuries occurring in the head region, compared with the upper extremity (range = 2 – 46%), lower extremity (range = 0 – 24%) and trunk/other (range = 0 – 16%) regions. There is marked between-study variability in the proportion of injuries reported in the head region, which appears to be at least partly caused by a lack of consistency in the incidence and recording of facial/scalp laceration and concussion/cerebral injury data that are then used for analysis in retrospective studies. Although injury in the head region accounts for the largest proportion of boxing injuries these injuries include cuts and nose bleeds, *i.e.* all boxing injuries to the head.

Concussion accounts for a much smaller amount because of the high incidence of facial lacerations and other less serious injuries. Therefore, the proportion of concussions appears similar to the proportion of injuries to the hand-wrist complex (hand, wrist, finger and thumb). Hand injuries can be severe when they occur in boxing, as common types include skier's thumb, boxer's knuckle, and metacarpal fractures. Whilst concussion is of concern, the incidence of concussion is similar to hand and wrist injuries, There is clearly a need for preventative measures to be developed to reduce hand injury in boxing as well as concussion, which is often the focus of prevention programmes.

2.3 Hand and Wrist injuries in Boxing

It is clear from the systematic review presented above that hand and wrist injuries inflict a high burden of injury on boxers. The following review examines these boxing related hand injuries in more detail.

2.3.1 The Nature of Boxing Injuries in the Hand and Wrist

2.3.1.1 Acute Ulna Collateral Ligament of the Thumb Strain (Skier's thumb)

Anatomy

The metacarpal phalangeal joint (MCPJ) of the thumb is a synovial joint situated between the first metacarpal and the first proximal phalange. The ulnar collateral ligament is the major support preventing abduction and hyperextension of the MCPJ.

Definitions

Skier's thumb is the popular designation for an ulnar collateral ligament tear at the first MCP joint following from an acute injury (51-54). Gamekeeper's thumb is an overuse injury due to the constant wringing of birds necks between index finger and thumb, causing a chronic instability of the first MCPJ. The terms are however sometimes used interchangeably.

Injury Mechanism

In boxing the thumb is particularly vulnerable because when the hand is in the boxing glove the thumb is maintained in the extended position. A misplaced punch may therefore produce a forced abduction of an extended thumb. This can overload the UCL causing partial or full tear of the ligament. The popular moniker for this injury is 'skiers thumb', the position of the hand in skiing is almost identical, with the fingers gripping the ski pole with the thumb extended (51-54).

2.3.1.2 Damage to the Soft Tissue of the Extensor Surface of the 2nd to 5th Metacarpophalangeal Joint (MCPJ) Boxer's Knuckle

Definition

The knuckles are defined as the extensor surface of the second to fifth MCP joints. The first reference in the literature to Boxers Knuckle is by Gladden in 1957 and referred to cases of damage to the extensor tendon mechanism or hood, of which a proportion also involved damage to the underlying joint capsule (55). While some authorities have continued to use this broad definition (56)(56)(56)(Melone et al., 2009)(Melone et al., 2009) some researchers have limited the term to cases where the joint capsule is damaged (with or without damage to the extensor tendon mechanism or hood) (57, 58) and others refer only to damage to the extensor tendon mechanism or hood (59). To be inclusive, for the purpose of this literature review Boxers Knuckle is defined as 'damage to the soft tissues of the extensor surface of the 2nd to 5th MCPJ'.

Anatomy

The knuckle consists of the metacarpal phalangeal joint this is an ellipsoid synovial joint between the heads of the metacarpal of the index, ring, middle and little finger, and the shallow concavities of the base of the proximal phalanx (60). Posterior to the capsule of the joint is the extensor hood mechanism which contains the extensor tendon of the finger. This is a single tendon in the middle and ring fingers but consists of 2 tendons for the index and little finger. The extensor hood has transverse fibers, the sagittal band, which stabilizes the extensor tendon so it can travel over the mid-point of the joint. This gives the greatest mechanical advantage when extending the finger (Illustration 2.14, 2.15, 2.16). The hood also has attachments to lumbricals and interosseous muscles, these muscles help perform fine movements of the fingers.

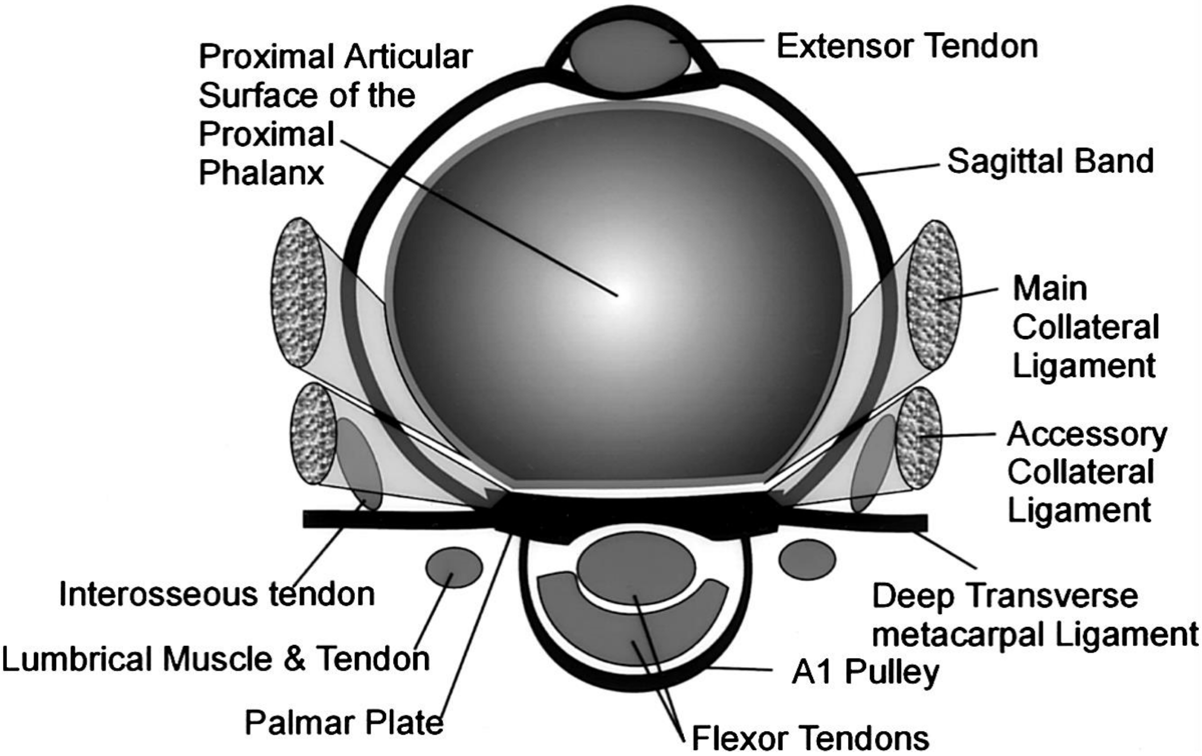

Figure 2.15 Transverse View of the Main Structures of the MCP Joint After Removal of the Metacarpal Head.(61)

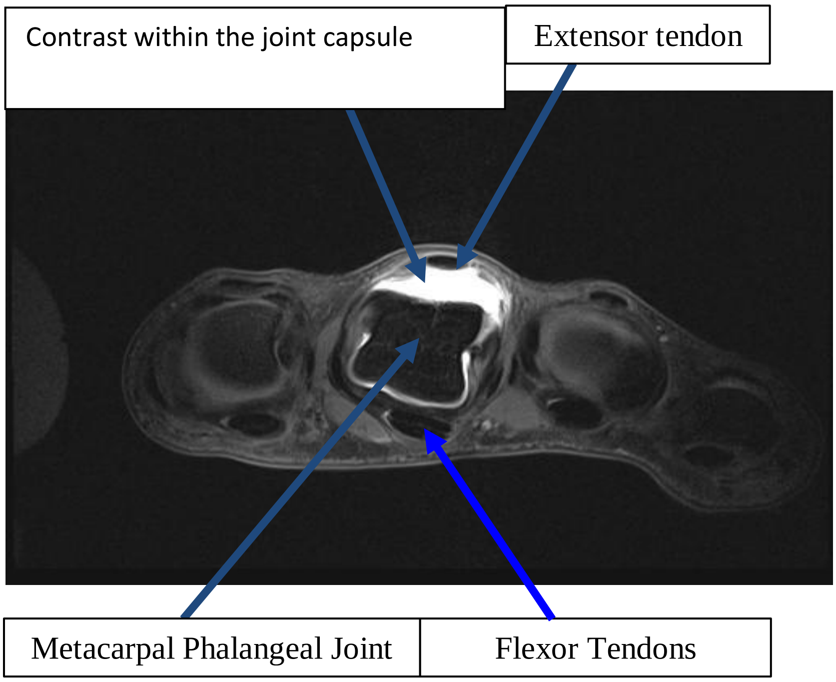

Figure 2.16 3T MRI scan of Metacarpal Phalangeal Joint

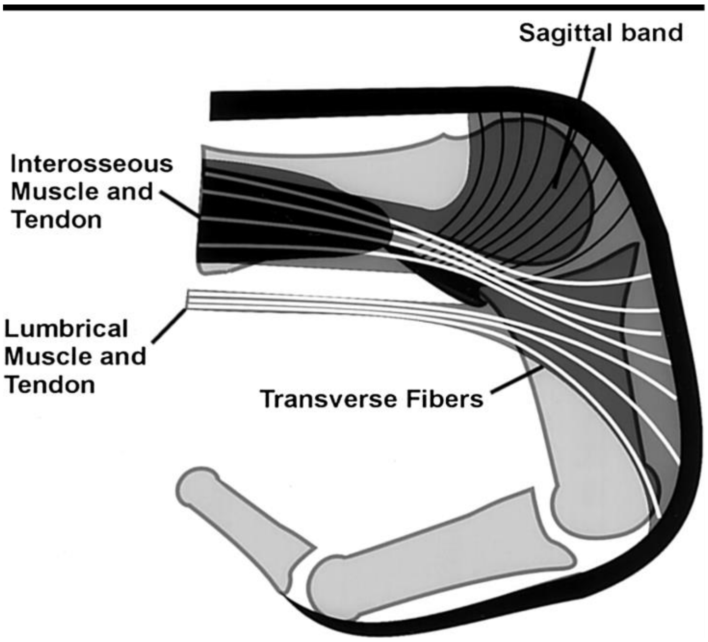

Figure 2.17 Extensor Hood. (61)

Injury Mechanism

In boxing, the extensor tendon mechanism or hood and the underlying joint capsule of one of the second to fifth MCP joints is damaged by direct impact to the knuckles, as occurs frequently in punching. Whether the soft tissues of the damaged MCP joint are injured purely by a distinct, acute trauma or whether the damage is the result of progressive weakening following repetitive impacts is currently unclear. Scalcione and colleagues assumed that such progressive weakening is routine (54). This has not yet been demonstrated and consequently remains the subject of investigation (55). Similarly, whether the extent of the impact is a key factor in determining the nature of the damage to the soft tissue, magnitude, frequency or deformity of tissues, is also unclear, although some researchers have assumed that a greater impact is responsible for damage to the underlying joint capsule than to the extensor tendon mechanism or hood (55).

2.3.1.3 Bennett's Fracture

Definition

Fractures to the base of the first metacarpal (i.e. involving the Carpo-Metacarpal joint (CMCJ) of the thumb) are relatively common in boxing (Chapter 4) (62) and are known as Bennett's fractures (63, 64). They are unstable, intra-articular fractures and since they typically involve at least some subluxation, they are often commonly termed Bennett fracture dislocations (63).

Anatomy

The thumb is formed of two phalanges (distal and proximal) and a metacarpal. The CMC joint is a synovial, saddle shaped joint between the base of the first metacarpal and the trapezium (a carpal bone) (60) the thumb CMC joint is also called the trapeziometacarpal joint. There are several ligaments that stabilize the trapeziometacarpal joint. The dorsoradial ligament is the most important stabilizer of this joint, although the superficial and deep anterior obliques, intermetacarpal, ulnar collateral, and posterior oblique ligaments also have key roles (65).

Injury Mechanism

Bennett fractures are thought to arise by indirect means, through the application of axial compressive forces to the distal phalange of the thumb that are transmitted through the proximal phalange to the first metacarpal (63, 64). In boxing the clenched fist is encased in a glove and the thumb is separated from the rest of the hand and held in an extended position. This leaves the thumb vulnerable to the axial loading required to produce a Bennett's fracture. The dislocation commonly associated with Bennett fractures occurs because the fracture line is intra articular. The anterior oblique ligaments remain attached to the small, proximal portion of the metacarpal in the normal, anatomic position (63, 64) the rest of the metacarpal subluxes dorsally, radially, and proximally (63, 64) in response to the action of the thumb extensor muscles.

2.3.1.4 Fracture of the Head of the 5th Metacarpal (Boxer's fracture)

Definition

Fractures of the fifth metacarpal (little finger) neck were originally thought to be so common in boxing that they have become traditionally known as "boxer's fracture" (66) however the incidence in boxers appears to be very low (62) as boxers tend to punch through the 2nd and 3rd metacarpals. This fracture may be better named the drunk punching a wall fracture. Although In his study of the incidence of different types of hand injury, Noble (16) also reported that such fractures were regularly observed.

Anatomy

The fifth metacarpal is generally more unstable than the index middle and ring finger metacarpals because it only has another metacarpal to stabilize it on one side. It is the most mobile metacarpal at the carpo metacarpal joint. It also has extensor carpi ulnaris inserting into the ulna side of the base (60). This tendon attaching to the little finger metacarpal can therefore exert a force on the fragments of fractured metacarpal neck (67).

Injury Mechanism

Boxer's fractures are thought to arise by indirect means, through the application of axial compressive forces to the head of the 5^{th} metacarpal(66). No direct biomechanical investigation has been performed to assess whether this is in fact the case and therefore it remains speculative. During boxing the 5^{th} metacarpal is only loaded if the punch is thrown or lands incorrectly. There is a need for ongoing research in this area.

2.4. Literature in Respect of Hand and Wrist Injury in Boxing

2.4.1 Introduction

As a contact sport, boxing has the potential to cause injury in participating athletes. Such injuries appear to occur most commonly to the head and the hand (3, 6, 7, 14). Consequently, many observational studies (3, 4, 6, 7, 14-16, 49, 50, 68), case studies (49, 69-71), clinical reports (48) and reviews (72) have reported on the nature and extent of boxing hand injuries, although no controlled trials have been performed in respect of either interventions to reduce injury or treatments following injury.

Additionally, other reviews of athletic injuries have described some of the hand injuries that commonly affect boxers (73). However, whether because of the high incidence of facial lacerations in comparison to other injuries (6), or because of medical concerns over the damaging effects of concussion (74), or because knockouts are recorded routinely unlike as in many other sports (75), many studies in the boxing literature have focused on head injuries and its subsequent implications (76) (77).

Thus, although hand injuries are very common in boxing (6), they seem to have been subject to a lesser degree of investigation. While previous reviews have discussed boxing hand injury as part of a wider discussion (72, 73), no previous dedicated review has been performed in respect of boxing hand injury, this is possibly because the concerns around injuries in boxing have focused on the head. Therefore, it was the purpose of this review to summarize the current state of the literature relating to hand injuries in boxing.

2.4.2 Observational Trials

The majority of studies performed in relation to the prevalence of boxing hand injury have been observational in design. Most studies have used data collected retrospectively (3-7, 16, 49) with only a few prospective investigations (14, 15).

Most observational trials have analysed hand injury as a subset of overall injury (3, 4, 6, 7, 14, 15) and only one has explored the nature of hand injury exclusively (16).

Two observational trials have been performed in relation to the treatment of hand injury in boxers (49, 50) and one has been performed to observe the effects of changing equipment type on injury reporting (68).

2.4.3 Hand Injury as a Sub-Set of General Injury by Region – Retrospective Studies

Studies that have analysed hand injury as a subset of overall injury have reported differing results, although hand injury does appear as a major injury type in most (3, 6, 7) but not all (4, 5) retrospective cross-sectional trials of boxing injury incidence.

The large differences between trials may arise because of heterogeneity between injury definitions both in respect of what constitutes any injury (the injury definition varied in each paper) and in respect of what is defined as "hand" injury (hand only or hand and Wrist, between boxing federation rules in different geographies (Australia, Italy and the USA), between amateur in comparison to the professional status of the boxers (in competition amateur boxers have poor hand protection compared to training and compared to professional boxers), and between the age and gender of participants.

Timm et al. (3) retrospectively examined injury data in relation to amateur boxers from the Olympic training centre in the US over a 15-year period from January 1, 1977 – June 30, 1992. When classified by injury location, 25% of injuries occurred in the upper extremity, 19% to the head or face, 15% to the lower extremity, and 9% to the spine. Timm concluded that most boxing injuries occur in the upper extremity.

Zazryn et al. (4) retrospectively collected injury data relating to boxing matches in Australia participated in by State of Victoria-registered professional boxers over a 16-year period between August 1985 – August 2001. When classified by injury location, they reported that 90% of injuries occurred to the head, face and neck, 7% to the upper extremities, 1% to the trunk, 0% to the lower extremity, and 2% were not specified. Thus, it was concluded that the head and face region was the most commonly injured part of the body and that the hand was the second most commonly injured body part.

Zazryn et al. (5) retrospectively collected injury data relating to boxing matches in Australia participated in by State of Victoria-registered professional boxers over an 8.5-year period from January 1997 – June 2005. They reported that open wounds or lacerations to the head and face comprised 62% of injuries; concussions represented 12% of injuries, while hand and finger injury accounted for only 7% of injuries.

Bledsoe et al. (6) retrospectively collected injury data relating to all professional boxing matches in Nevada, USA over a 1.5 year period between September 2001 – March 2003. In respect of boxing matches in which male boxers participated, when classified by injury location, it was found that 51% of injuries occurred to the face (excluding non-laceration injuries to the nose, eye and ear), 17% to the hand, 15% to the eye, 5% to the nose, and 2% to the ear. Thus, it was concluded that facial injuries accounted for the majority of injuries in professional male boxers in the US, while hand injuries were the second most common. However, head injury was not noted as a possibility, despite the observation that 51% of fights ended in either a technical knockout or knockout. This may therefore reflect differences in the definitions of head injury between this and other similar studies (3, 4, 7).

Bianco et al. (7) retrospectively collected injury data relating to female boxing matches in Italy between January 2002 – October 2003. They found the face was the hand or wrist accounted for 25% of injuries. However, the total number of injuries was very small (20 injuries) because the incidence of injury was also small (97% of boxers studied had no post-match injury), which makes these data hard to interpret.

As discussed in the systematic review professional boxers have good hand protection but no head guards to protect their faces. These findings illustrate this difference with amateur boxers having a high number of hand and wrist injuries but a low number of facial injuries compared with professional boxers.

2.4.4 Hand Injury as a Sub Set of General Injury by Region – Prospective Incidence

Studies that have analysed hand injury as a subset of overall injury have reported differing results, although hand injury does appear as a major injury type in some (14) but not all (15) prospective cross-sectional trials of boxing injury incidence.

The considerable differences between trials may have arisen because of heterogeneity between injury definitions (both in respect of what constitutes any injury and in respect of what is defined as “hand” injury), between boxing federation rules in different geographies (Italy, Ireland, and Australia), between professional status of the participants, and between the age and gender of participants. It is also noteworthy that the number of participants, the duration of the trials, and the number of injuries recorded in some of the trials were very small, making it difficult to draw strong inferences about the type of injuries that are most common from their results.

Porter and O’Brien (14) prospectively collected injury data relating to boxing matches in Dublin participated in by 147 amateur boxers over a 5-month period between November 1992 – March 1993. They analysed injuries both in competition and during training. When classified by injury location, they reported that 52% of injuries in competition occurred to the head (defined solely here as mild cerebral concussion), 20% of injuries occurred to the hand or wrist, and 20% of injuries occurred to the face (defined here widely to include the ear, nose and eye).

It was therefore concluded that during competition the most common injury was concussion, while facial and hand/wrist injuries together joint second most common. In training, the injury distribution by region was very different, with 41% of injuries occurring in the lower extremity, 35% occurring in the hand/wrist, 10% of injuries occurring to the face, and no concussions occurring at all. It was noted that the nature of lower extremity injury incurred was of the overuse type similar to that seen in distance runners, which may reflect the type of conditioning work that was being performed. Zazryn prospectively collected injury data relating to boxing matches in 33 amateur and 14 active professional boxers registered in Victoria, Australia over a 1-year period in 2004 – 2005 (15).

While injuries incurred during training and competition and between amateur and professional athletes were recorded separately, only a small number of hand injuries (21 in total) were reported overall and therefore interpretation of the data was not carried out.

2.4.5 Hand Injury by Type – Incidence

Only one study has explored the incidence and nature of boxing hand injuries. Noble assessed 100 consecutive boxing injuries to the hand in 86 boxers presenting either post-match or in the office of the South African Boxing Board of Control (16). Hand injuries were divided into three different areas (Figure 2.17): (A1) the thumb, including the scaphoid and carpometacarpal joint; (A2) the wrist, including both the bases of metacarpals 2 – 5 but excluding the parts included in section A1 for the thumb; and (A3) the fingers, comprising the phalanges and the remaining metacarpals, excluding the parts included in section A2 for the wrist. While this detail regarding the exact definitions of individual hand injury types is beneficial, it is unfortunate that these classifications cannot be directly compared with the incidence of hand, wrist, and finger injury reported in other studies (3-7, 14, 15, 49, 50, 68) because of differences in the definitions used in each case.

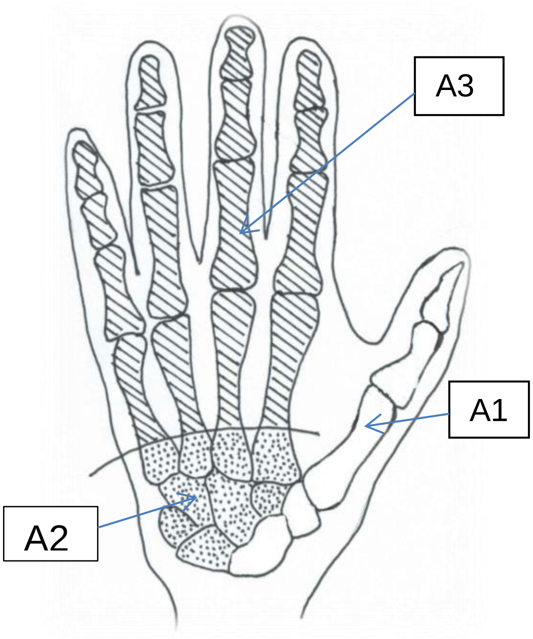

Figure 2.18 The Noble Hand Classification

Noble reported that 39% of all injuries occurred in A1, 35% in A2, and 26% in A3 (16). In A1, 23% of all injuries involved strains of the ulnar collateral ligament of the metacarpophalangeal joint of the thumb, caused by forced thumb abduction 10% involved carpometacarpal joint injuries of the thumb. In A2, 12% of all injuries involved inflammation of carpometacarpal joints 2 – 5 and 12% involved persistent subluxation of one or more metacarpal bases, possibly as a result of excessive wrist flexion during punching. In A3, 12% involved painful hypertrophy of the metacarpophalangeal joint soft tissues and underlying extensor tendon (i.e. “boxer’s knuckle” injury), while 8% involved metacarpal fractures, most likely because of impact forces.

Based on these observations, Noble (16) suggested that specific measures could be taken to reduce the incidence of such injuries in each area. o prevent the injuries occurring in A1, it was proposed that gloves should be made that allow the placement of the thumb within the fist and not lying alongside.

For A2, it was suggested that greater fixation of the wrist should be performed, as well as better instruction on punching technique, to avoid excessive wrist flexion.For A3, it was suggested that reducing impact forces by increasing padding would be the only method that would be helpful.

2.4.6 Case studies

Case studies have provided additional evidence in support of surgical treatment for ‘boxer’s knuckle’ injury (49, 69-71) and also identify ultrasound as a potentially beneficial diagnostic tool. Four such case studies describe damage to the soft tissues of the metacarpophalangeal joint and underlying extensor tendon (i.e. ‘boxer’s knuckle’ injury).

Gladden (69) was the first to describe this condition in boxers in 1957 and presented four cases (two heavyweights and two light heavyweights), of which three were treated surgically and one conservatively but all nevertheless successfully.

More recently, Bents et al. (71) presented a case study in a collegiate boxer at a military academy in whom the sagittal bands of the extensor tendon mechanism were unaffected but the extensor tendons themselves were dislocated, accompanied by an underlying capsular tear.

The sagittal bands are transversely oriented ligaments that are part of the extensor retinacular system and which surround the extensor digitorum tendon and the superficial interosseous tendons on both sides (78, 79). The sagittal bands are the primary stabilizer of the extensor digitorum at the metacarpophalangeal joint (78, 79). Thus, the case was unusual, as disturbance to the underlying extensor tendon would normally be preceded by sagittal band disruption. The case was treated surgically to repair the capsular tear and realign the extensor tendons and the subject made a successful recovery. The researchers did not speculate on the cause of this unusual injury.

Although not performed in relation to boxers, Lopez-Ben et al. (70) reported on three cases in which dynamic ultrasonography was used successfully to assist in the diagnosis of traumatic and non-traumatic extensor tendon dislocations. In two cases, ultrasound following injury revealed soft tissue swelling of the metacarpophalangeal joint and displacement of the common extensor tendon sheath in the affected joint. During surgery, ulnar dislocation of the extensor tendon was observed and a radial sagittal band longitudinal tear was repaired.

Arai et al. (49) described two case reports of “boxer’s knuckle” injury. In the first, an initial non-boxing injury was incurred and then forgotten for 3 months before presentation because of pain and tendon snapping when making a fist. Surgical intervention revealed a significantly ruptured joint capsule and tendon. After 16 weeks, there was no pain and/or tendon snapping but grip strength was reduced. In a second case, a lightweight professional boxer felt pain subsequent to a punch and developed hand pain as a result. Surgery was performed 6 weeks post-injury, which revealed extensive scarring of the extensor tendon, a torn joint capsule, and a torn and degenerated sagittal band. Debridement of the scar tissue and synovium was performed and the joint capsule and sagittal band were repaired. Return to sport occurred after 3 months and treatment was deemed satisfactory at 2-year follow-up.

These case reports show that there is no standard pattern to boxers knuckle tissue injury. They all present as a painful swollen knuckle, however the pathology can be a mixture of capsular, sagittal band and extensor hood damage with all or none being diagnosed as a boxers knuckle.

2.4.7 Clinical Reports

One clinical report has detailed impressions of injury incidence and treatment methods. McDougall (48) presented a description of clinical treatment for various boxing injuries. It was noted that common injuries included soft tissue damage at the bases of the metacarpals of the index and middle fingers, fractures of the metacarpals themselves (mainly the little finger but also the index finger and of the thumb), and tears of the ulnar collateral ligament of the first metacarpophalangeal joint (i.e. the thumb) as a result of not tucking the thumb under while punching. In contrast, less common injuries noted included: injury to the interphalangeal joints (as they are stable when the fist is closed), thumb dislocation, and wrist sprains (unless the boxer falls while training or in the ring).

2.4.8 Current Guidance

In respect of boxing hand injury, current guidance provided to sports medicine physicians notes that “the most common fractures are those of the first metacarpal” and that these most commonly arise from “a poor punching technique, where the thumb is not correctly positioned opposite to the index and middle fingers” (80).

There is little evidence to support these statements. Rather, there is some evidence to support a higher incidence of damage (not limited to fractures) in decreasing order: to the thumb (including the scaphoid and carpometacarpal joint), to the wrist (including the bases of metacarpals 2 – 5), and to the fingers (i.e. the phalanges and remaining metacarpals) including “boxer’s knuckle” injury (16). Where “boxer’s knuckle” is indicated, there is some evidence to suggest that it may affect the middle finger most often, followed by the little finger (49, 50).

Boxing hand injury does not appear to comprise exclusively fractures but also includes a high proportion of ligamentous tears, joint subluxation, and painful soft tissue hypertrophy or inflammation (16).

Finally, there is currently no evidence to suggest that poor punching technique is a risk factor for injury, as no trials have been performed connecting any kinematic features of technique with altered injury incidence.

2.4.9 Further Research

Based on the limitations apparent within this literature review and the need to supply current guidelines with more detailed evidence-based recommendations, it is apparent that further research into boxing hand injury is required in several areas, as shown in the table below (Table 2.8).

Research area	Limitation of current literature	Proposed investigation
Injury definitions	Current definitions of what constitutes injury in boxing are diverse.	Injury definitions should be adopted that prescribe exactly what process has to be undertaken in order for an injury to be recorded.
Injury definitions	Current definitions of what constitutes hand injury in boxing are diverse.	Hand injury definitions should be clarified to specify whether the fingers, thumb and wrist are included or excluded.
Incidence of hand injury	Current retrospective cross-sectional trials are limited by small numbers of injuries as outcomes because of small sample sizes.	Retrospective analysis should be performed of the injury data for larger squads of boxers.
Incidence of hand injury	Current prospective cross-sectional trials are limited by small numbers of injuries as outcomes because of small sample sizes.	Prospective analysis should be performed of the injury data for larger squads of boxers
Incidence of hand injury over time	Limited previous studies have cast doubt on whether safety measures have the intended beneficial effects. However, multiple measures were tested and limited outcome measures used.	Detailed prospective analysis should be performed of the injury data for two consecutive periods in which individual different safety measures are used.
Factors affecting hand injury risk	It is unclear what risk factors might predispose boxers to hand injury. Various risk factors have been proposed but not investigated (e.g. type of gloves worn and punching technique used). Risk factors for overall injury seem to be age and number of competitions participated in.	Prospective trials should be performed, assessing the relative risks associated with various anthropometric (e.g. knuckle profile or wrist girth) and biomechanical measurements (e.g. kinematics of arm movements during punching).
Factors affecting hand injury risk	Some evidence suggests that certain parts of the hand might be more at risk of injury than others (e.g. middle finger in Boxer's knuckle).	Methods should be developed to help identify the biomechanical reasons for such increased risks (e.g. are there differences in pressure during punching between middle finger metacarpal and other metacarpals?).
Treatment	It is unclear exactly what treatment is being provided in many areas relating to boxing hand injury.	Retrospective analysis should be performed of treatment data of boxing hand injury in order to establish current practices.
Treatment	It is unclear exactly which treatment practices are optimal for boxing hand injury.	Retrospective analysis should be performed of treatment data of boxing hand injury in order to establish which practices appear to be associated with the best outcomes.

Table 2.8 Table of Current Research Limitations and Proposals for Further Investigations.

2.4.10 Conclusions

Boxing injuries appear to occur most commonly to the head and the hand (3, 6, 7, 14). While head injury is the more frequently investigated type of injury, it is apparent from observational studies of boxing injuries by body region that there is also a high incidence of hand injury, (3, 6, 7, 14), albeit with very large differences in outcomes between studies, indicating a high degree of heterogeneity. Such heterogeneity may have arisen not least because of differences between definitions used in the studies of injury in general and of hand injury in particular.

In respect of boxing hand injury, incidence of damage may occur in decreasing order to the thumb, wrist and fingers (including "boxer's knuckle" injury) (16). Among hand injuries, "boxer's knuckle" has been most extensively studied and it appears that the middle finger, followed by the little finger, are most commonly subject to this particular injury (49, 50). Both observational studies (49) and case studies (49, 69-71) support the use of surgical treatment for this condition in competitive boxers.

Overall, however, literature is extremely limited regarding the exact nature of boxing hand injury, the parts of the hand that are most commonly injured, the biomechanical and anthropometric risk factors that predispose some individuals or parts of the hand to injury more than others, and those treatment methods that are most successful. This is important because in chapter 3 it is shown that hand injuries are the cause the greatest morbidity in the GB boxing team and result in the longest time out of training and competition.

Consequently, further studies are recommended to provide better definitions of boxing injury in general and hand injury in particular, to establish injury incidence based on such definitions, to explore injury risk factors, and to identify optimal treatment methods. To capture exposure data the injuries per number of punches made/received, injuries per hour of training/competition or injuries per round should be recorded.

2.5 The Force Exposure of the Hand and Wrist in Boxing

2.5.1 Introduction

Noble (16) reported that 12% of boxing injuries involved painful hypertrophy of the MCP joint soft tissues and underlying extensor tendon (i.e. “boxer’s knuckle” injury), while 8% involved metacarpal fractures, most likely because of impact forces. Noble suggested that specific measures could be taken to reduce the incidence of such injuries. For MCP joint injuries Noble suggested that reducing impact forces by increasing padding would be the only method that would be helpful.

2.5.2 The Biomechanics of Punching

The impact forces resulting from the punch of an elite boxer can be very large (81-83). Smith and colleagues (81) developed a boxing dynamometer by combining a tri-axial force measurement system and a boxing mannequin and used it to compare the maximal punching force of 7 elite, 8 intermediate and 8 novice boxers during straight punches. Maximal punching forces were 4,800, 3,722 and 2,381 Newton (N) for the rear hand in the elite, intermediate and novice groups, respectively.

Joch and colleagues (82) similarly compared 24 elite, 23 national-level and 23 intermediate-level boxers and reported punch forces of 3,453, 3023 and 2932N, respectively.

Smith (83) reported impact forces during straight punches in senior England international amateur boxers with the lead hand of 1,722N and 1,682N to the head and body, respectively, and punches with the rear hand of 2,643 and 2,646N to the head and body, respectively . Smith (83) also reported impact forces during hook punches with the lead hand of 2,412 and 2,414N to the head and body, respectively, and punches with the rear hand of 2,588 and 2,555N to the head and body, respectively .

Walilko and colleagues (84) assessed punching force in 31 Olympic boxers using similar apparatus and found that punch forces ranged from 1,990 to 4,741N while the mean force was 3,427N. Atha and colleagues (85) recorded punch forces of

4,096N in a world-ranked heavyweight boxer during punches directed at a cylindrical, instrumented target.

It seems highly plausible that these forces that are borne mainly upon the knuckles are responsible for the serious hand injuries that have been reported in several case studies (50) and which have lead to the term “boxer’s knuckle” becoming widely used (69).

However, whether it is purely the magnitude of these impact forces or whether the distribution of such impact forces during punching are of any importance is unclear. Moreover, there is currently no standard method for ascertaining the distribution of the impact forces across the knuckles during punching.

2.6 Risk of Death in Amateur Olympic Boxing (AOB)

Injury rates in Olympic boxers are generally low compared to other contact sports and confined to the hands, arms, head and brain. The injuries causing most concern are those to the brain. These injuries can be classified from concussion through mild, moderate and severe brain injury to death. The less severe forms of brain injury are often difficult to attribute directly to boxing. There are fewer uncertainties with death. The following section will examine the evidence pertaining to the incidence of death and head injury in boxing.

Whilst tragedies do occur in amateur boxing, such as the death of an amateur boxer reported in Greece in 2004 (86). These events are fortunately rare. It is clear from Table 2.9 that amateur boxing has a low fatality rate (a third that of rugby and similar to ice skating). Work published by the sports council (87) did not separate amateur boxing, professional boxing and wrestling also confirms the low death rate (table 2.9). In horse racing, Turner et al describes the death rate, as ‘*strikingly high’* (1 death every 100000 rides in Great Britain) (88). Furthermore, a study examining Australian Rules football reported a *high death rate* (25 deaths in 30years in the state of Victoria, Australia) (89). In rugby union there are a significant number of deaths reported although some of these are the result of fatal injuries to the neck rather than head injuries *per se* (90, 91).

Activity	Numbers of fatal accidents	Estimated death rate per 100 million occasions of participation
Air sports	102	>640
Climbing	88	>793
Motor sports	99	146
Sailing	33	44.5
Fishing	104	37.4
All other water sports	103	67.5
Rugby	12	15.7
Soccer	34	3.8
Cricket	5	3.1
Hockey	1	2.9
Self - defense	3	1.4
Boxing/Wrestling	3	5.2
Fencing	1	>6.3
Ice-Skating	3	4.7
Horse Riding	97	34.3
Track and Field	1	1.0
Other running	18	1.2
Weightlifting	3	0.2
Gymnastics	4	4.8
Squash	4	0.9
Tennis	2	0.7
Badminton	0	0.0
Table Tennis	1	0.2
Golf	1	0.1

Table 2.9 Fatal Accident Rates per 100 million Occasions of Participation for All Persons Aged 15 Years or Older 1982-1989, England and Wales, by Activity (87).

In American grid iron football there were four hundred and ninety two deaths recorded over a fifty five year period (92). In snowboarding head and neck injuries are a leading cause of death and disability (93) and even in baseball, in 5 to 14 year olds there is a small but steady number of fatalities (94). It is difficult to filter out what proportion of these deaths are from head injuries. It is clear that the rate of all-cause mortality (Table 2.9) is higher in many other sports and in a number of other sports the death rate from head injury is higher than those reported in amateur boxing.

2.7 Risk of Acute Head Injury in Amateur Olympic Boxing (AOB)

The difficulty in reviewing the literature on acute head injury and concussion is that the definition has changed over the years. In an attempt to address this, a consensus statement was made on concussion in 2001 at the first international conference on concussion (95). Since this time there have been 3 further international conferences the last being in 2012 (96), even during this short space of time the definition of concussion has changed. In the most recent statement it was recognised that the, symptoms and signs may evolve over a number of minutes to hours and that in some cases symptoms may be prolonged.

Rates of concussion in AOB boxing appear low compared with other impact sports. A review of central nervous system injuries in sport and recreation by Toth and colleagues (97) gives a concussion rate of 0.58 concussions per 100 athlete exposures in amateur boxing, an exposure is defined as a boxing contest. Toth however, fails to quote the source of this statistic as many of the papers used in the boxing section of this review (97) are up to 48yrs old (average time since publication 18 years). Despite this potential confounding factor the rate quoted is lower than other sports described in the same paper.

Rugby union has a high rate of concussion (98), with recorded rates of 4.5 concussions per 100 athlete exposures in this case matches played , 3.8% of all rugby injuries are concussion (99), and 10% of rugby union injuries are head injuries (100). A review of concussion in professional rugby union players (101) gives a concussion rate of 0.59 per 100 athlete exposures, this is the same as is quoted for amateur boxing (97), however it is interesting to note that an amateur boxer may not get 100 exposures in his entire career whereas a professional rugby union player will accumulate 100 exposures in 2 competitive seasons.

Ice hockey also has a high recorded concussion rate (102) with levels of 6.6 concussions per 1000 player hours. This compares to 0.8 concussions per 1000 hours in international amateur boxing. A publication reporting snow blading injuries (103) described 11% of all injuries attributed to concussion. Soccer has a recorded concussion rate of 0.15 per 1000 exposures (104).

It is clear that head injury can occur in any form of sport (105). Direct studies on concussion rates in amateur boxers have shown that amateur boxers very rarely suffer concussion during contests (106), a finding which is borne out by information collected from international boxing tournaments where knockouts and the need for the referee to stop a contest due to blows to the head (RSC (H)) were reported as very low (107).

2.8 Chronic Traumatic Brain Encephalopathy (CTBE) in AOB

2.8.1 Background

The term ‘Punch Drunk’ was first introduced by Martland in 1928 (108). Chronic traumatic brain injury has since been described in more detail. In the early stages of the condition, symptoms reflect plaques and neurofibulary tangles seen on histological examination of the brain affecting the pyramidal, cerebellar, and extrapyramidal systems. In the later stages, cognitive and behavioural impairment predominate. About one third of cases are progressive with increased parkinsonian type symptoms and dementia like neuro degeneration (109-112).

A landmark paper published by Corsellis (113) presented evidence of histological changes in the brains of boxers. The study examined the brains of 15 individuals who had boxed at some stage during their life. Interviews were carried out with the deceased’s relatives or peers. The interviews were not limited to individuals who knew the deceased during their boxing career and were conducted retrospectively. The purpose of the interview was to establish symptoms of punch drunk syndrome and to obtain a life history. Seven of the 15 individuals had drunk alcohol to excess, one had syphilis, four had suffered strokes, and four had been known to have experienced serious head trauma outside the ring (one had more than one serious head injury outside the ring, one incidence requiring several months as an in-patient).

Corsellis (113) noted that the brains of this group contained neurofibrillary tangles with the absence of senile plaques, unlike Alzheimer’s disease which has both neurofibrillary tangles and senile plaques. The author also noted a loss of pigment cells from the substantia nigra. Caution is warranted in the interpretation of this paper; however, as the author attributed all the observed changes to boxing and not to any of the other experiences these individuals had suffered during their lives. It is interesting to note that none of the three amateur boxers in this study had the changes the author attributed to boxing. Two of the three subjects that had boxed as amateurs did not drink and did not have memory loss, nor did they have the neurofibrillary tangles that Corsellis (113) attributed as a histological marker in ‘punch drunk’ syndrome. The third subject that had boxed as an amateur had an Alzheimer’s pattern of neurofibrillary tangles and plaques; this subject was reported to have suffered from dementia however the tone of the paper suggests it was due to this subject having boxed in the past. In contrast, Corsellis’ own criteria would suggest that this was due to a normal pattern of Alzheimer’s disease as would the clinical findings.

While Corsellis demonstrates a unique pattern of histological changes in the brains of individuals who had previously boxed, care is warranted when attributing these changes solely to boxing. These boxers had fought in the period 1900-40, and eight of them were national champions or world champions in their weight division. The boxers in this cohort had very high boxing exposure. The number of career fights ranged from 400 to 700. Many boxers also worked in fairground boxing booths post retirement from the prize ring and had up to 30 or 40 fights each day over several years. Although these fights would have been with gloves at this time medical supervision would have been non-existent. These individuals were also exposed to other events during their lives such as high alcohol consumption, severe head injuries outside the boxing ring and syphilis. Further examination of the amateur boxers within this cohort demonstrates no histological changes suggestive of the ‘punch drunk’ syndrome.

The first paper to examine an amateur boxer’s risk of Chronic Traumatic Brain Encephalopathy (CTBE) was Thomasen (114). A group of 53 amateur boxers who were regional or national champions between 1955 and 1965 were examined. Boxers were matched for age, education and vocabulary with 53 former first division footballers. Subjects were assessed using electroencephalogram (EEG), neurological and neuropsychological testing. The results demonstrated no significant difference between the amateur boxers and footballers. It must be noted, however, that the potential relationship between repetitive heading of a heavy ball and brain injury (115, 116) may mask comparisons in brain function in this study. An additional finding in this study (114) was a statistically significant difference in the finger tapping test of the dominant hand, with the amateur boxers being significantly slower than the footballers ($P<0.05$). This finding has been replicated in other studies (117) and appears to be worse with increased exposure to boxing. The relationship between finger tapping response and brain damage is difficult to assess in the boxers (118), however, given the chronic damage to the fingers is directly associated with repeated punches it is not surprising that boxers with more contests would have a slower finger tapping response.

TITLE OF PAPER	AUTHOR	YEAR	N	Control (N)	R	P	REPORTED FINDINGS	LEVEL
Punch Drunk	Martland	1928	1	0	Yes		Boxers can suffer from a post encephalitic syndrome- ‘Punch Drunk’	5
The aftermath of boxing	Corsellis	1973	3	0	Yes		The 3 amateur boxers in this study did not have the changes associated with CTBE.	5
Neurological, electroencephalographic and neuropsycological examination of 53 former amateur boxers	Thomassen	1979	53	53	Yes		No difference between boxers and controls, except reduced finger tapping in dominant hand of boxers	3
Few head injuries found in academic boxing study	Leywold	1982	7000	0	Yes		68 head injuries recorded none resulted in neurological dysfunction	5
Is chronic brain damage in boxing a thing of the past	Kaste	1982	14	0	Yes		Looked at various measures of brain function. Only a few amateur boxers had squeal	5
Blood creatine kinase isoenzyme BB in boxers	Brayne	1982	16	16		Yes	CK-BB was raised following boxing compared with track cyclists.	2
Brain damage in modern boxers	Casson	1984	5	0	Yes		The author concludes that 87% of boxers get chronic brain damage.	5

Boxers, CT, EEG and neurological evaluation	Ross	1987	53	0	Yes		The author uses the number of bouts as a control. 10 of the boxers were amateur. The author states that no evidence of CTBE in amateurs.	4
Magnetic resonance imaging in amateur boxers	Jordan	1988	9	0	Yes		Boxers KO'ed showed no difference on CT&MRI pre and post bout.	4
Clinical Neurological examination, neuropsycology, electroencephalopathy and CT in active amateur boxers	McLatchie	1987	20	20	yes		Neurological findings correlated with increasing number of fights.	3
A neuropsycological study of amateur boxers	Brooks	1987	29	19	Yes		Controls matched for age ethnicity and education. No evidence of significantly impaired performance in amateur boxers	3
Neurobehavioural functioning and magnetic resonance imaging findings in young boxers	Levin	1987	2	13	Yes		Reported no difference between pre and post bout MRIs	4
CT and MRI imaging comparisons in boxers	Jordan	1988	9		Yes		Boxers KO'ed showed no difference on CT&MRI pre and post bout.	4
Does Swedish amateur boxing lead to chronic brain damage. A retrospective medical, neurological and personality trait study	Hagland	1990	47	50	Yes		No difference between boxers and controls	3

Does Swedish amateur boxing lead to chronic brain damage. A retrospective study with CT & MRI	Haglund	1990	47	50	Yes		No significant difference between boxers and controls. NB More carvum septum pelucidi in controls	3
Does Swedish amateur boxing lead to chronic brain damage. A retrospective neurological study.	Haglund	1990	47	50	Yes		No difference between boxers and controls except in EEG findings which may be a sign of slight brain damage in amateur boxers	3
Amateur boxing injuries at the US Olympic Training Centre	Jordan	1990	447		Yes		6.5% of injuries were cerebral. 28of 29 recorded as concussions, 26 of these recorded as mild	4
Does Swedish amateur boxing lead to chronic brain damage.	Murelius	1991	47	50	Yes		No difference between boxers and controls except decreased finger tapping in the dominant hand.	3
Neuropsycologic test performance in amateur boxers	Heilbronner	1991	23	0		Yes	Cognitive function before and after a bout showed no observer differences between winners and losers. Showed minor changes in cognitive function in amateur boxers compared to controls	2
The significance of diagnostic imaging in acute and chronic brain damage in boxing. A prospective study in amateur boxing using MRI	Holzgrafe	1982	13	0		Yes	5 boxers with neurological signs had no significant changes on MRI. Felt that MRI at this stage could not clarify the development of CTBE.	5

Prospective study of central nervous system function in amateur boxers in the United States	Stewart	1994	484	0		Yes	Retrospectively boxing exposure showed significant changes but within the study no significant changes were found	3
Neuropsycological investigation of amateur boxers	Butler	1993	86	78		Yes	No significant difference between boxers and controls	2
Cerebral perfusion and psychometric testing in military amateur boxers	Kemp	1995	41	27		Yes	Controls performed better on psychometric testing until educational attainment was weighted for then the results are identical.SPECT scan showed more abnormal results in controls	2
Incidence and severity of injuries resulting from amateur boxing in Ireland	Porter	1996	20	20		Yes	0.7 injuries per boxer per year. Cerebral injuries only reported in competition, most mild	2
Controlled prospective neurological assessment of active experienced amateur boxers	Porter	1996	20	20		Yes	Amateur boxing not associated with CTBE	2
Acute intracranial boxing related injuries in US Marine corps recruits: Report of 2 cases	Ross	1999	180 000	0	Yes		2 significant head injuries in 8 years. Risk of serious head injury is relatively minimal in a well supervised instructional programme.	3
Acute traumatic brain injury in amateur boxing	Master	2000	38	28		Yes	Neurosycometric testing before and after boxing showed an ATBI pattern in boxers compared to controls	2

A nine year controlled prospective neuropsycological assessment of amateur boxing	Porter	2003	20	20		Yes	Amateur boxers show relative preservation/and/or improvement in psychometric testing compared with controls	2
A prospective controlled study of cognitive function during an amateur boxing tournament	Moriarity	2004	23	0		Yes	Cognitive function measured before and after event. No observed difference between winners and losers. Showed only minor changes in cognitive function in amateur boxers compared to controls	2
Diffusion anisotropy changes in the brains of professional boxers.	Zhang	2006	49	19		Yes	Significant changes in all the boxers compared with controls	2
Unrecognised ringside concussive injury in amateur boxers	Moriarity	2012	200	0		Yes	Concussion was missed in 1.7% of boxers assessed clinically by a doctor post bout	2
A prospective study of punch biomechanics and cognitive function for amateur boxers	Stojsih	2010	55	0		Yes	There was a significant decrease in delayed memory after sparing in both men and women. After 24 hours there was no significant difference on any of the neurocognitive measures	2
Neurological assessment and its relationship to CSF biomarkers in amateur boxers	Neselius	2014	30	25		Yes	Raised CSF NFL in the absence of of psychometric changes suggesting that there may be axonal damage in the absence of neuropsycometric changes	2
Increased CSF levels of phosphorylated neurofilament heavy protein (NFLh)following bout in amateur boxers	Neselius	2013	30	25		Yes	Raised CSF NFLh in boxers following a bout compared to controls. APO e4 did not seem to influence NFLh levels	2

CSF-biomarkers in Olympic boxing: diagnosis and effects of repetitive head trauma.	Neselius	2012	30	25		Yes	Olympic boxing may induce CSF biomarker changes that suggest minor central nervous injuries	2
Olympic boxing is associated with elevated levels of the neuronal protein tau in plasma.	Neselius	2013	30	25		Yes	Olympic boxing is associated with elevation of tau in plasma.	2

Table 2.10 Review of Literature on Concussion in Amateur Boxing R=Retrospective P=Prospective

Table 2.10 Notes:

N is the number of subjects in the study group; CON is the number of control subjects; RET is retrospective study; PRO is prospective study; Am is Amateur

The Level of evidence rules were as follows:

1. Double blind, prospective, controlled study.
2. Prospective controlled cohort study, with single or no blinding.
3. Retrospective cohort study, non-consecutive study or without consistently applied reference standards.
4. Case-control study, poor or non-independent reference standard.
5. Expert opinion without explicit critical appraisal, or based on physiology, bench research or ‘first principles’.

Of interest is that Thomasen (114) included three pairs of monozygotic twins all of whom boxed. Despite the individuals within the pairs having different exposure to boxing, no difference between the pairs was observed. This is the only recorded comparison of identical twins reported in the literature. The evidence from the monozygotic twins, although limited in numbers (three pairs of identical twins), is very powerful, and as the twins are genetically identical, differences between the pairs would almost certainly be environmental, in this case different exposures to boxing between the pairs of twins.

Thomasen (114) concluded that amateur boxing posed no risk of serious and permanent brain damage. The paper is limited due to the low subject numbers (53 amateur boxers and 53 controls). However, the papers strengths lie in the fact that it is controlled, and that the controls are matched for education and vocabulary. In a number of other studies, education and vocabulary are not matched. This is important as this factor has a large weighting on neuropsycometric testing (119). Legwold (120) published a brief report examining the injuries incurred by 7000 recruits at West Point Military Academy over seven years. The study reported 68 head injuries none of which resulted in 'neurological dysfunction'. The paper failed to report detail about the type of head injuries sustained. The absence of detailed clinical histories in Legwold's paper is replicated in a large number of other studies recording injury rates in amateur boxers that makes the results difficult to compare with other amateur boxing studies and also to compare with other sports.

The low incidence of head injury observed by Legwold (120) concurs with the Estwanik et al, (11) study, the authors examined head injuries in the 1981 and 1982 USA amateur boxing federation National Championships. The injury statistics for 547 consecutive bouts reported that 4.38% were stopped because of head blows of which only a small number resulted in unconsciousness or an inability to recall the injury. The authors quote a personal communication indicating a head injury rate of 1.43% based on 6050 bouts. Jordan and colleagues (10), examined amateur boxing injuries incurred at the United States Olympic training centre. Twenty nine (6.5%) injuries were recorded as cerebral, 28 of which were concussion and 26 of the concussions as 'mild'. Unfortunately the authors failed to record how many boxers were involved or over what time period the injuries occurred.

The largest study of head injury rates in amateur boxers was published by Ross (121) who studied U.S. Marine Corps recruits over an eight year period. Of the 180,000 recruits that boxed, only three serious head injuries were recorded (1 in 60,000 participants). The author failed to record how many bouts each boxer had completed, concluding that the risk of serious head injury in a well supervised, instructional boxing programme is relatively small.

Kaste et al. (117) reported neurological examination, computerized tomography (CT) brain scan, EEG, brainstem evoked potential (BEP) psychological testing and ‘other symptoms’, in 14 boxers, 8 of whom were amateurs. Of the 8 amateur boxers none had abnormal neurological, psychological or ‘other symptoms’. One of the 8 amateur boxers had an abnormal CT scan (cavum septum pellucidum) the significance of which is uncertain (111). One of the amateur boxers had an abnormal BEP and four had abnormal EEG’s. It should be noted that an abnormal false positive EEG rate of 20% has been reported. The rate of false positive results increasing as the population age reduces (122). In this study the amateur boxers are younger (mean age 26) compared to the professional boxers (mean age 38) so it is possible that there would be a higher abnormal EEG rate in the younger amateur boxer group because of the increased rate of false positive results, however, compared to normative data this is still a high abnormal rate. Interestingly, despite the greater exposure to boxing in the group of professional boxers the number of abnormal EEG’s was lower in the professional boxing group. Care is warranted in the interpretation of this paper due to the low subject numbers and absence of control subjects.

Of interest Kaste also notes that the amateur boxers had a better than average education and worked in a higher level occupation than either their siblings or their parents. The author dismisses this finding, however, believing that the other findings of brain damage outweigh this advantage. No explanation is offered to how it is possible that the brain damaged boxers can outperform their non-boxing siblings.

In a similar study, Ross (123) examined CT and EEG, with psychometric testing and neurological examination in 53 boxers (10 amateur). Ross used the number of bouts as a controlling factor, the author concluded that increased numbers of bouts resulted in greater brain damage, however caution must be exercised as the author does not use all 53 boxers in every aspect of the study, for example the largest group is the group that had CT scans. The group is divided into 4 depending on the number of bouts, this left one group with n of 5. The smallest numbers are in the neurological examination group (n=24) this group is divided into 3 depending on the number of bouts. The different boxers used in each group and the different categorisation of the number of bouts, makes the results difficult to interpret. The author also states that he was unable to demonstrate significant chronic brain damage in the amateur boxers tested.

Casson (124) published a landmark paper that has been frequently cited in the debate regarding the high prevalence of brain injury associated with boxing, concluding that 87% of boxers had definitive evidence of brain damage. Care is warranted, however, as this paper demonstrates a number of key shortfalls in the research methods employed. It is a highly heterogeneous group of amateur and professional boxers with an age range of 25-60, including ex-boxers and current boxers. Educational attainment ranged from college graduates to junior high school, with the number of bouts ranging from 0 (sparring only) to 240 bouts (with an average of 83 bouts) and the length of boxing career ranging from 3 months to 22 years. If the numbers in the cohort were high the above could be considered an advantage, however Casson (124) studied a small cohort of boxers (n=18) in the absence of control subjects using CT, EEG, neurological exam including mental state, and a neuropsychological test battery. Eight of the eighteen boxers were reported to have abnormal CT scans with 3 having cavum septum pellucidum. The ability of CT to detect chronic brain damage in boxers at this time is now in doubt (125) as is the clinical relevance of a cavum septum pellucidum (111).

Only 13 of the 18 boxers were assessed using EEG of which five were diffusely abnormal and two were moderately abnormal. Five of the boxers were deemed to have clinical neurological changes with 3 having what the author described as *clinical organic mental syndrome,* this he states is *manifest by disorientation, confusion and memory loss.* Casson (124) fails to explain the seriousness of this condition. Casson (124) stated that all the former boxers were, at the time of testing, in full time employment in the civil service or private industry. The results of the neuropsychological testing can be regarded as unsafe as it is known that this is sensitive to intellectual ability and age (118, 126), neither of which were controlled for in this study. The significant methodological short falls suggests that this paper should be interpreted with caution and is unlikely to offer strong evidence of chronic brain damage in amateur boxers, despite its general acceptance within the medical community.

Haglund (127-129) undertook a retrospective study examining various aspects of brain function variables including: neurological examination, personality trait study, CT and MRI images and neuropsychological study. Haglund examined 47 former Swedish amateur boxers and a control group of soccer and track and field athletes matched for age. The participants were also interviewed about background variables including: career, education, employment, marital status, medical history, exposure to organic solvents, use of alcohol and drugs, and general life style. The number of boxers employed in this study although small, was greater than most other studies. Furthermore, investigators were blinded to participant group. The results of this study demonstrated only one statistical difference existed between the boxers and controls that of repetitive finger tapping in the dominant hand and this finding seemed to increase with increasing number of bouts. This finding, may be a physical artefact of the damage caused peripherally to the joints of the hand following the repeated trauma of boxing rather than central damage to the brain (118).

Heilbronner (130) carried out neuropsychological tests on 23 amateur boxers before and after an amateur boxing event. Compared to their pre contest performance, the boxers produced a lower score on verbal and incidental memory but improved on executive and motor functions following the boxing bout. Interestingly, there was no difference between winning and losing boxers following their contest. The numbers for this study were again small and there was no control group. The boxers were not followed up to assess how long it took to return to baseline following the competition. Thus, no conclusions can be drawn about chronic traumatic brain encephalopathy from this paper as all of the amateur boxers could have been suffering from a mild concussion.

In conclusion, medical evidence presented in the aforementioned studies relating to rates of head injury and death in amateur boxers suggests the injury rates and deaths are low. As boxers today have relatively short careers. More recent studies of professional boxers find that 95% of registered boxers have fewer than six fights in their careers.

As the exposure to blows to the head has decreased so markedly in modern boxing it is possible that CTBE is now an historic boxing disease.

2.8.2 Nature of Injury Identification of CTBI

The detection of changes in the brain is essential for the detection of CTBE. Studies have included; clinical history and examination, structural examination including CT (computerized tomography), MRI (magnetic resonance imaging) and SPECT (single photon emission CT scanning), and functional testing which includes psychometric testing. Psychometric testing appears to be the most sensitive way to detect subtle changes in brain function. The following section critically examines studies using various techniques employed in the assessment of injury reported in the literature.

2.8.2.1 Brain Imaging Techniques

Jordan and Zimmerman (131) examined brain MRI in 9 amateur boxer's pre and post bout who had been knocked out at the golden gloves amateur boxing tournament, demonstrating no difference between pre and post bout scans. A more recent paper from the same authors (131) examined 21 boxers (4 amateurs) using MRI and CT The authors reported that MRI picked up more structural abnormalities than CT. They suggested that one abnormality in an amateur boxer may have been due to boxing. However, this was a retrospective study so could not be proven. Jordan and Zimmerman (131) concluded that MRI is a more sensitive and specific tool when examining abnormalities compared with CT.

Holzgraefe (132) examined 13 amateur boxers before and after contests. Five boxers demonstrated neurological signs of dysfunction without any evidence of haematoma or other structural abnormalities on MRI. The author concluded that MRI could not confirm the development of encephalopathy. Unfortunately, the boxers in this study were not followed up to examine how long before the neurological exam returned to normal. Levin (133) carried out a similar study in 13 amateur boxers reporting no difference between pre and post bout MRI The negative findings of both these studies is supported in a review article (125) that examined the neuroimaging evidence for chronic brain damage in boxers concluding that one off scans were of no help in detecting chronic brain damage and that serial scans would be better. However no studies with a sufficiently large cohort were available in the literature. This review (125) concluded that there was not yet a radiological technique that could identify chronic brain damage in boxers. In another review, McCrory (111) concluded that there was no evidence that a cavum septum pellucidum correlates with neuropsychological or clinical abnormality.

Kemp (119) examined cerebral perfusion and psychometric testing in military recruits, 41 boxers and 37 controls (non-boxing sportsmen). Thirty-four boxers and 34 controls underwent technetium-99m hexamethylpropyleneamineoxime single photon emission computerized tomography (Tc-99m HMPAO SPECT) cerebral perfusion scans. The author noted that there were more anomalies in the boxer's scans than in the controls. Further, it was suggested that as amyloid protein deposition is associated with abnormal vasculature, as is ischemic patho-physiological changes known to occur after closed head injury, HMPAO SPECT scanning may demonstrate brain damage earlier than CT or MRI. On psychometric testing the author found the boxers presented with lower scores than the controls, although the controls chosen were undergoing medical assistant training and had on average 30% more 'O' levels than the boxers. Educational status is known to be a confounding factor in psychometric testing and the author recognises this fact by weighting the results accordingly. The results may have been safer, however, if the controls had been matched for intellect and education. Interestingly, the boxers with the abnormal SPECT perfusion scans did not correlate with the boxers with the low scores on psychometric testing. Despite the theory, there is no direct evidence that SPECT cerebral perfusion imaging demonstrates evidence of changes of chronic traumatic brain encephalopathy. Zhang (134) showed that diffusion ansotrophy in a group of 49 professional boxers compared with 19 controls showed significant changes in all the boxers compared with controls, whereas conventional MRI showed various radiological changes in only 7 of the professional boxers compared with the control group and the changes were considered clinically insignificant radiologically.

2.8.2.2 Psychometric Testing

Butler (118) examined 86 amateur boxers and 76 controls in a prospective study. The amateur boxers and the control group were followed over a period of 6 months to 2 years. Significant differences in baseline measurements in 8 of the 12 psychometric tests used in this study were explained by the educational differences between the two groups. The controls (rugby players and water polo players) were drawn from an undergraduate population whereas many of the boxers had not completed their full time education. As no data on IQ had been gathered this factor could not be assessed.

Over the longitudinal period of the study there was no significant difference between the amateur boxers and the controls. Butler (118) concluded that amateur boxing does not cause long-term brain damage. The fact that the boxers were not matched for education and IQ is a weakness of the study, however the prospective nature of the study and the relatively large numbers together with the use of a control group are significant strengths compared with previous studies employing psychometric testing.

In 1994 a large prospective study was carried out in the United States of America involving 484 amateur boxers (135). This study used psychometric testing to investigate CTBE in amateur boxers. Retrospective baseline testing appeared to demonstrate poorer scores in boxers that had participated in more contests. In the prospective element of the trial, however, there were no significant changes observed in the test results. Care is warranted; however, as follow up was limited to two years. The author felt that this may not be a long enough time period for the chronic traumatic brain encephalopathy to develop. Further, no control group was employed in this study.

A similar longitudinal study, following 20 boxers, was published by Porter (14). Although the study had a small cohort, the study did have a control group which was matched for age and education. Initial findings were published after two years and, similar to the study of Stewart (135), boxers demonstrated no difference in psychomotor testing and importantly, no difference between the amateur boxers and controls was reported. The author conducted a follow up study at nine years (136). The author reported no significant difference between the two groups although the amateur boxers tended to perform better than the controls. The Porter study (136) is stronger than the Stewart study, although fewer boxers were recruited, (20 vs 484 respectively), the Porter study (136) employs well matched controls and had follow up over a protracted period.

There are two studies examining neuropsycometric changes in amateur boxers, before and after bouts of boxing. Matser (137) carried out a prospective controlled trial of 38 amateur boxers and 28 sporting, non-boxing controls. The author carried out psychometric testing on all the athletes, the amateur boxers then participated in a bout of boxing and the controls exercised for the same length of time, the two groups where then re-tested. The author observed a pattern of acute traumatic brain injury in the boxers that was not present in the controls. The author failed to follow up the groups therefore the duration of the altered psychometric assessment was not reported. A second, similar study was carried out by Moriarity (106). In this paper the author studied a group of 84 boxers, carrying out baseline neuropsycometric testing, and re-tested following a seven day boxing tournament. This study was controlled with a group of 30 non-boxing athletes. Moriarity reported no difference between the boxers and the control group.

Moriarity carried out a further prospective observational study (138) of 200 competing amateur United States of America collegiate boxers. Differences between pre and post-bout computerised cognitive assessment tool (CCAT) scores were calculated, this is a reliable and validated tool for assessing concussion (139). Screening for clinical evidence of concussion was carried out by a ringside physician. Of the boxers not diagnosed with concussion 17 (10.6%) failed their first post-bout CCAT; 12 (71%) of whom passed a repeat test. Of the remaining 5, 2 boxers (1.3%) showed evolving slowing in cognitive performance typical of a concussion.

Stojsih, et al. (140) examined head acceleration data and cognitive function in 55 boxers 26 males and 29 females during sparring. On one of the measures, delayed memory, there was a significant decrease after sparing in both men and women. After 24 hours there was no significant difference on any of the neurocognitive measures. There was no association between head impact and the results of cognitive testing.

2.8.2.3 Biomarkers

Cerebrospinal fluid (CSF) biomarkers have been examined in boxing as a measure of damage to the brain (141-144) . The biomarkers studied in relation to boxing are tau protein and neurofilament light polypeptide (NFL). It is thought that tau protein derives from non-myelinated cells of cortical neurons, whereas NFL derives from myelinated cells (142). Both tau and NFL reach a peak in the CSF at 4-10 days following trauma to the head (141, 143).

The rise in NFL appears to be greater than tau suggesting it may be a more sensitive measure of brain damage than tau protein (143). It is also known that the level of tau is proportionate to the size of the brain lesion and the outcome of patients with severe head injuries (145-147). Studies in amateur boxers that have not been knocked out have shown increased levels of tau, this normalises at 8-12 weeks if no further blows to the head are received (141, 143).

NFL is raised in amateur boxers exposed to trauma and levels in the CSF increases with increasing numbers of blows to the head (141, 143).

Neselius et al. studied the CSF taken from 30 amateur boxers 1-6 days following a bout and after 14 days rest, and compared to 25 matched controls who had one CSF sample taken. Blood samples were drawn and analysis subsequently conducted for both cohorts during the same study. The results from this study were published in a series of papers. One study showed raised CSF NFL in the absence of psychometric changes in the group of x30 amateur boxers compared to 25 controls (148), suggesting that there may be axonal damage in the absence of neuropsycometric changes.

The weakness of this study was the lack of base line studies for the neuropsycometric tests. When other biomarkers were examined Total tau (T-tau), NFL, glial fibrillary acidic protein (GFAP), and S100 calcium-binding protein B (S-100B) were all raised in more than 80% of the boxers (143), it was noted that NFL and GFAP Phosphorylated Neurofilament-Heavy Chain (pNFH) was also found to be significantly raised in the boxing cohort compared to the control group (149). Also in this paper it was noted that APO e4 was not associated with the rise in pNFH. A study examining the level of T-tau in blood showed significant rises compared to the control group (144). A weakness in this series of studies is that the rise in biomarkers is not related to any change in brain function. So it is not clear how significant the rise in biomarkers is to the functioning of the brain now or in the future.

2.8.2.4 Genetics

The other major risk factor for chronic traumatic brain injury may be genetic. Studies show that boxers with the apolipoprotein E4 (apoE4) allele are susceptible to chronic neurological deficits (150). Male boxers who have 12 or more professional fights, as well as the ApoE4 allele are 16 times more likely to have neurological deficits than those who have had 12 or more professional fights and do not have the allele. However the numbers in the study were small (n=30) and there was no control group.

2.9 Equipment effects on injury incidence

While no controlled trials have been performed in respect of the difference that various types of equipment makes to injury incidence, one study did observe the effects of changing boxing regulations. Schmidt-Olsen et al. (68) assessed whether or not certain equipment modifications (unlimited length of hand bandage, voluntary boxing helmets, and heavier gloves for boxers >149 pounds (67.6Kg) affected the frequency of matches ended early by the ringside doctor to preventing injury. The data were gathered from reports submitted by the ringside doctors during three seasons, 1983 – 1986. In the first of these three seasons, no boxers wore helmets, all wore 8oz (227g) gloves, and a fixed length of hand bandage was stipulated. These three features were modified for safety reasons and by the third season it was estimated that 60% of boxers used helmets, 10oz (284g) gloves for boxers >149 pounds (67.6Kg) was compulsory, and the length of hand bandage allowed was unlimited. It was found that these safety measures had no effect on the number of fights that were stopped early on the grounds of preventing injury. It was unfortunately not possible to assess the effects of these measures on the number or type of injuries by region, as these data were not always recorded by the ringside doctor.

The introduction of head guards, together with enhanced energy absorbing materials, help to prevent cuts and damage to the eye, however it is still unclear if they have a significant role in reducing concussion (68). The improvement in the energy absorbing properties of the materials in the head gear, gloves and the covering of the ring, which is a high density polyurethane foam (151), aid in the prevention of head injuries if boxers fall and strike their head on the canvas.

2.10 Rule Changes in Olympic Boxing

It is possible that changing the rules of competition may affect the health of the boxer. Bianco and colleagues (2) examined the changes in the rules from 1952 to 2011 to see how this affected the boxer's health (Figure 2.17 and Table 2.11)

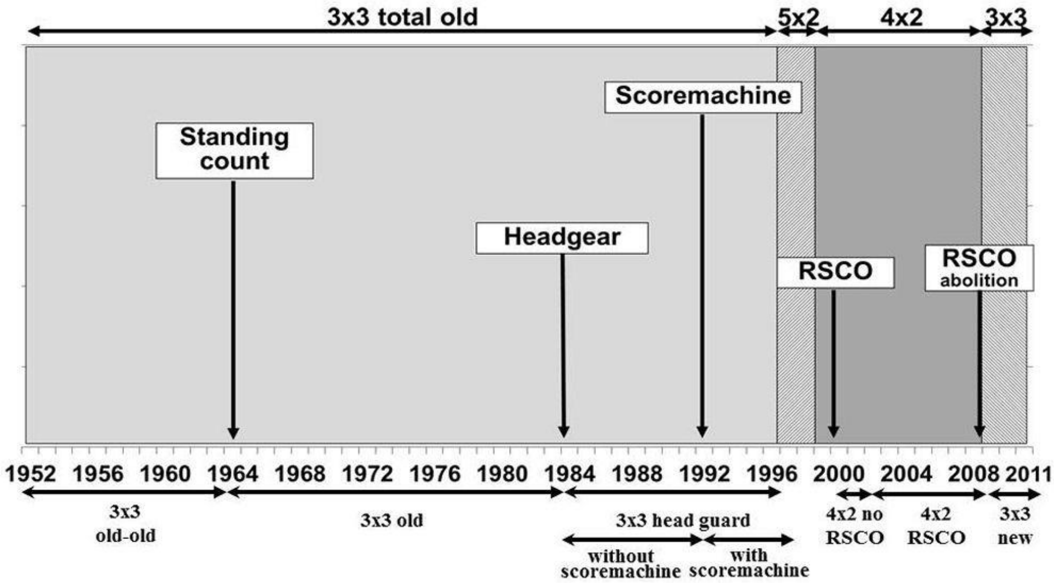

Figure 2.19 Major Rule Changes in Amateur Boxing from 1952 to 2011.
In the upper part of the panel, the bout length formula has been indicated. In the upper and lower parts are shown the different subgroups in which the boxing bouts were divided for the analysis. RSC(O), referee stops contest (outclassed).

Date	Rule Change	Description of Rule Change	Effect of Rule Change on Health
1964	Standing Count	The referee was allowed to start an 8 sec count if a boxer was in difficulties for any reason without the boxer having been knocked to the canvas.	Significant reduction in the KO rate (from 7.6% to 5.9%). The results of other medical interests substantially unchanged, but there was an unexpected significant increase) of matches ended due to medical reasons (mainly lacerations).
1984	Head Guards introduced for all international competitions	Introduction of head guards at the Los Angeles Olympics and for all international competition	The number of RSC(I) reduced by 3 fold, mainly due to the reduction in facial cuts. Although the number of Knockouts reduced the number of RSC(H) and RSC increased, so that the total number of stoppages due to blows to the head increased from 17.3% to 21.8%
1992	Computerised Scoring	This changed the scoring system so that clear single blows were scored	This system stopped boxers throwing body shots as they did not score. So the vast majority of the blows were aimed at the head. Knockouts reduced considerably but the total of KO, RSC(H) and RSC remained the same
1997	Bout length changed to 5x2 minute rounds	Length of round changed from 3x3minute rounds to 5x2minute rounds	Significant drop in KO rate
1999	Bout length changed to 4x2 minute rounds	Length of round changed from 5x2 minute rounds to 4x2 minute rounds	Reduction in RSC and RSC(H), the combination of These results and KO the lowest ever
2000	Outclassed Rule RSC(O)	If one boxer out-scored the opponent by 15 points the bout would be stopped the loser being deemed to have been outclassed.	A rule to protect boxers but no change in overall stoppage rate
2009	Return to 3x3 and RSC(O) abolished	The length of round increased to 3 minutes and the number of rounds reduced to 3	No Change in overall stoppage rate
2013	Head Guards removed for all international competitions	Boxers went back to not wearing head guards for the first time in 30 years	RSC, RSC(H) and KO remained the same or may have reduced on preliminary figures. The number of facial cuts increased significantly

Table 2.11 Rule Changes from 1952 to 2013. Referee Stopped Contest (RSC) Referee Stopped Contest (Head) RSC(H). Referee Stopped Contest (Injury) RSC(I).1964-2009 from Bianco (2) 2013 from Chapter 7 in this thesis.

2.11 Conclusion

This literature review has examined the literature pertaining to boxing as it related to this thesis. The volume of literature understandably concentrates on the concerns around concussion and the potentially life changing effects of chronic traumatic encephalopathy. It would appear from the literature review that the risk, from boxing, of chronic traumatic encephalopathy is low. The literature on other boxing injuries especially those to the hand and wrist which keep boxers out of the sport for prolonged periods of time has not been published, however, injuries to hand and wrist appear to be amongst the most prevalent.

The specific research questions examined in this thesis are what is the rate of injury in the GB Boxing squad, Can the force pattern at the knuckle be calculated following a punch? Has the removal of head guards increased the rate of concussion in Olympic boxing?

The overarching objective is to increase the knowledge of boxing injuries and implement injury prevention measures to improve the health of boxers.

3.0 Injuries in the Great Britain Boxing Squad 2005 – 2009

3.1 Introduction

Recent studies have assessed injury location and injury rate in both amateur and professional boxing competition and, to a lesser extent, during training. A review of the literature indicates that the greatest proportion of injuries in boxing occur to the head and face (see chapter 2.2). A retrospective study of 545 professional boxers recorded 214 injuries in 907 competitive fights over 8.5 years: an injury rate of 23.6 per 100 fights (5). Open wounds or lacerations to the head and face comprised 62% of injuries, concussions 12%, and hand and finger damage 7%. A similar retrospective study recorded 195 injuries in 524 fights over 18 months recorded an injury rate of 17.1 per 100 fights, or 3.4 per 100 boxer-rounds (6). In this case, facial laceration accounted for 51% of all injuries, followed by hand injury (17%), eye injury (14%), and nose injury (5%). These findings are unsurprising as they record professional boxers during competition, where they do not wear any form of head protection, but wear hand wraps that afford much more protection than the Amateur Olympic Boxing (AOB) equivalent.
In contrast, there have been reports that head and face injuries do not account for the largest proportion of injuries in AOB boxing. Fifteen years of training and competition injury data from AOB boxers of the Olympic Training Center (USA) shows that 25% of injuries occurred in the upper extremity and 19% to the head or face (3). The discrepancy between these findings may relate to differences between AOB and professional boxers.

Injuries have also been reported, not just in competition, but also in training (when injury patterns may be different). Porter and O'Brien (14) prospectively collected injury data over a 5-month period in 147 amateur boxers and analysed the data separately for training and competition. In competition, head and face injuries predominated: 52% of injuries occurred to the head (concussion only), 20% of injuries occurred to the hand or wrist, and 20% of injuries occurred to the face (including the ear, nose and eye). In training, however, most injuries occurred elsewhere: 41% were recorded in the lower extremity, 35% occurred in the hand/wrist, and only 10% of injuries occurred to the face, with no incidents of concussion. In addition to this apparent conflict in the literature regarding the commonest sites of boxing injury, there have been few, if any, reports regarding the differentiation of recurrent and new injuries. Furthermore, few studies have reported on the duration of injuries in each case.

In order to reduce injuries in boxing, there is therefore a need to understand:

(i) where injuries most commonly occur; (ii) whether the location of injuries differs depending on whether athletes are in training or in competition; (iii) whether injuries are more likely to be new or recurrent; and (iv) the impact of different injuries on time lost from training or competition. Accordingly, 5 years of prospectively gathered longitudinal injury data from the Great Britain (GB) boxing squad in both training and competition without interruption were investigated.

3.2 Methods

The participants included all male boxers on the GB boxing squad at any time between 1 January 2005 and 31 December 2009. Injury data relating to these participants for the same period was released for publication by the English Institute of Sport and the British Amateur Boxing Association, both of whom gave permission to publish their data following the 2012 Olympic Games. Data relating to the number of minutes spent competing during this period was gathered for each athlete individually from the boxers records on their boxing cards or from publicly available information.

No data were recorded for the number of minutes spent in training for individual boxers in the same period. An injury was defined as any musculoskeletal condition that prevented the boxer from participating in either training or competition for more than 24 hours. Injuries were coded using a modified Orchard Sports Injury Classification System (version 10) (152) which recorded: the location of injury; the body region affected by the injury; description of the injury; duration (number of days injured) of each injury; participation when injury occurred (training or competition); and whether the injury was new or recurrent. Recurrence of an old injury was defined as the repeated report of an injury with the same code as the previous injury. Injuries were recorded prospectively by the GB medical team on a standard Excel spread sheet.

3.3 Statistical Methods

All demographic (age, and weight classification), participation (training or competition), and injury information (description, location, type, duration, and whether recurring or non-recurring) was entered into an Excel spreadsheet (Microsoft, Seattle, USA). All statistical tests and analysis were performed using R (153) by importing data directly from Excel.

Chi square tests were performed to identify significant differences in respect of the numbers of injuries incurred in different athlete, participation or injury categories. Where overall significant differences were found for these variables, Z scores were calculated to identify the individual differences. Z scores were appropriate as the entire population of the male GB boxing squad was included for the purposes of data collection. Multiple regression analysis was used to assess differences in respect of the duration of injury across anatomical locations. Significance was accepted at $p < 0.05$ for all comparisons. All data are presented as mean ± standard deviation (SD).

3.4 Results

3.4.1 Participants

Sixty-six boxers (aged 22.0 ± 2.5 years) were members of the GB boxing squad during the relevant period. The mean duration that each boxer was a member of the squad was 2.0 years and the duration of membership ranged from 1 – 5 years (boxers are given a one year rolling contract). The total number of boxer-years on the GB boxing squad in the relevant period was 131.5 years. In the cohort, there were boxers in each weight category from 48kg (light fly weight) through to over 91kg (Super Heavy Weight).

3.4.2 Injuries: Athlete Characteristics

Two-hundred and ninety-six injuries were recorded in the GB boxing squad in the relevant period. Injuries were sustained in 40 out of the 66 boxers (60.6%). Each injured boxer sustained a mean of 7.4 injuries. A chi square test revealed significant differences in respect of the number of injuries sustained across the weight classes (Table 3.1) ($X^2 = 90.1$, $p \leq 0.05$). However, analysis of Z scores did not identify any individual weight classes that sustained a significantly greater number of injuries when analysed by absolute numbers of injuries per weight class or by numbers of injuries per boxer per weight class (all Z scores were between 1.96 and -1.96, thus $p > 0.05$).

Weight (Kg)	48	51	54	57	60	64	69	75	81	91	91 +	Total
Number of Boxers	9	6	6	6	8	7	7	8	3	4	2	66
Number of injuries	30	5	50	26	37	23	28	31	11	37	18	296

Table 3.1 The Number of Injuries in Each Weight Class.

3.4.3 Injuries: Anatomical Location

A chi square test revealed that there were significant differences in the number of injuries sustained at different anatomical locations (X^2 = 338.6, p =<0.05). The numbers of injuries by anatomical location are provided in Table 3.2, along with the associated duration of injuries. Analysis of Z scores showed that injuries occurred significantly more often at the hand (Z score = 3.6) than at other anatomical locations. There were no other significant differences between anatomical locations. The Z scores for the number of injuries in each anatomical location in the squad during the relevant period are shown in Figure 3.1 below.

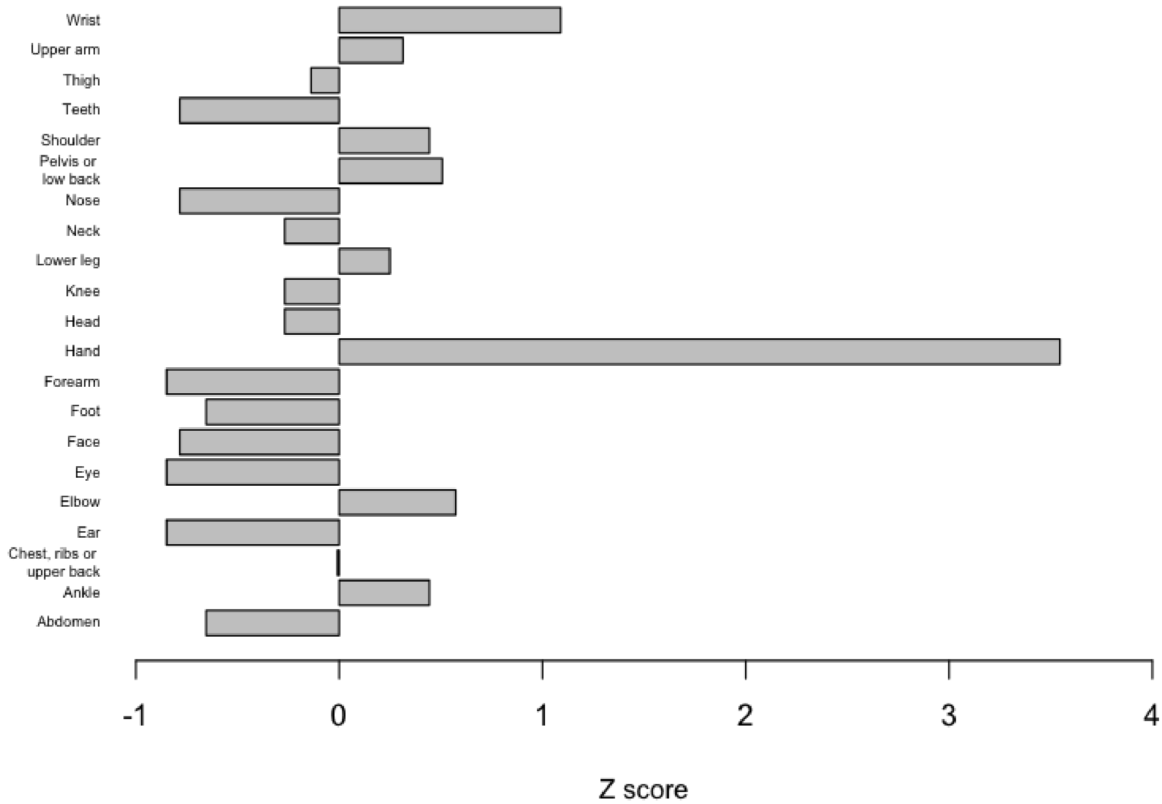

Figure 3.1 Z Scores for the Number of Injuries in Each Anatomical Location in the GB Boxing Squad, 2005 – 2009.

Location	Number of injuries	Average Duration of injuries in Days (Range in Days)
Abdomen	4	28.5 (5-77)
Ankle	21	22.4 (1-63)
Chest, ribs, upper back	14	24.4 (4-77)
Ear	1	2.0 (0)
Elbow	23	34.9 (3-165)
Eye	1	370.0 (0)
Face	2	7.0 (2-16)
Foot	4	16.0 (3-35)
Forearm	1	32.0 (0)
Hand	69	39.0 (4-150)
Head	10	15.6 (2-37)
Knee	10	21.0 (5-43)
Lower leg	18	19.4 (4-46)
Neck	10	38.6 (2-133)
Nose	2	9.0 (2-12)
Pelvis, low back	22	44.9 (3-450)
Shoulder	21	21.2 (2-111)
Teeth	2	14.5 (5-24)
Thigh	12	9.8 (3-23)
Upper arm	19	18.8 (2-97)
Wrist	31	60.2 (3-244)
Total	**296**	28.5 (1-450)

Table 3.2 Number and Duration (in Days) of Injuries in Each Anatomical Location in the GB Boxing Squad, 2005 – 2009

3.4.4 Injuries: Competition or Training

A chi square test revealed that there was a significant difference between the number of injuries sustained in competition and in training (X^2 = 49.3, p $\leq$0.05). Out of the 296 injuries sustained (Figure 3.2 Table 3.3), a higher number (n = 208, 70.4%) was sustained during training than in competition (n = 88, 29.6%).

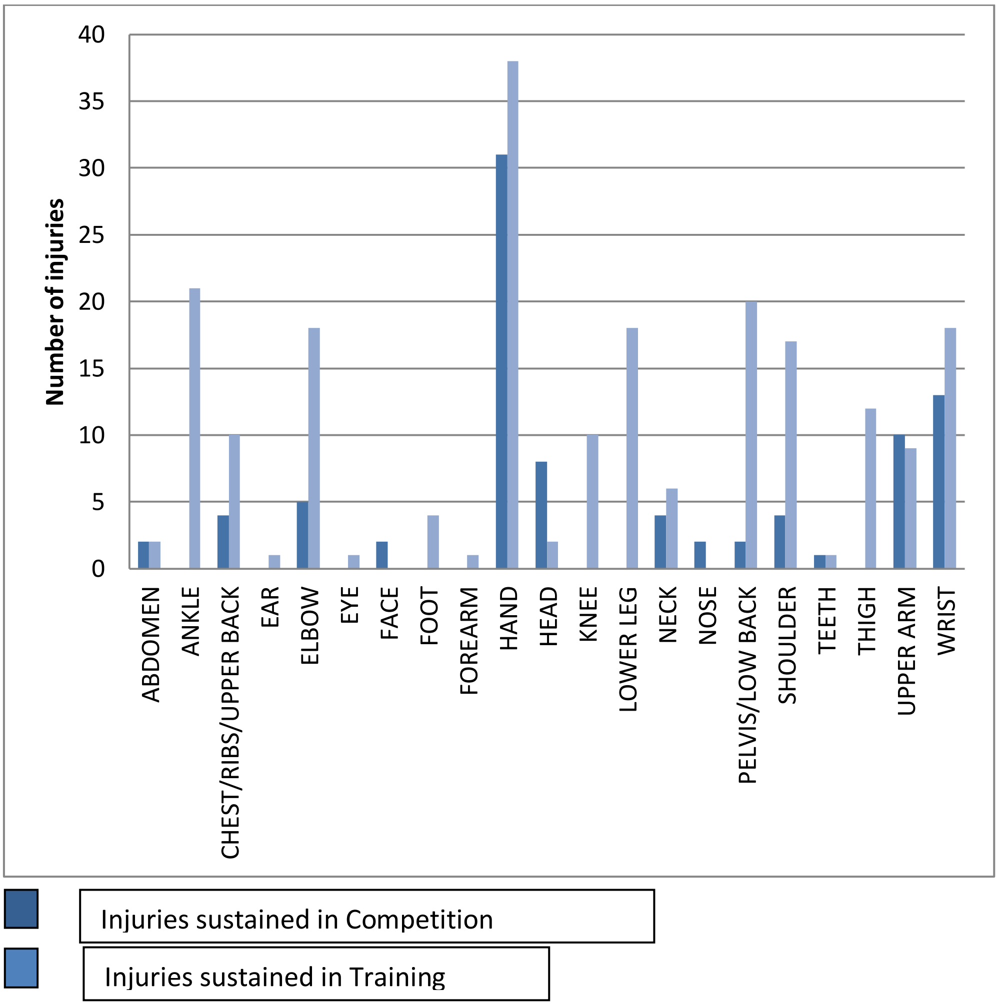

Figure 3.2 Injuries Sustained in Training and Competition

Location	Competition	Training
Abdomen	2	2
Ankle	0	21
Chest/Ribs/Upper Back	4	10
Ear	0	1
Elbow	5	18
Eye	0	1
Face	2	0
Foot	0	4
Forearm	0	1
Hand	31	38
Head	8	2
Knee	0	10
Lower Leg	0	18
Neck	4	6
Nose	2	0
Pelvis/Low Back	2	20
Shoulder	4	17
Teeth	1	1
Thigh	0	11
Upper Arm	10	9
Wrist	13	18
Total	88	208

Table 3.3 Table Showing the Number of Injuries at Each Location in Competition and Training

Chi square tests revealed that there were significant differences in the number of injuries sustained at different anatomical locations in both training (X^2 = 196.4, p<0.05) and competition (X^2 = 242.3, p<0.05). Analysis of Z scores showed that there were significantly more injuries in the relevant period at the hand in both training (Z score = 2.8) and in competition (Z score = 3.8) than at other anatomical locations. There were no other significant differences between anatomical locations in either training or competition. Hand injuries as a proportion of total injuries in training and competition were 18.2% and 35.2%, respectively. The charts below set out the Z scores for the number of injuries in each anatomical location in training (Figure 3.3) and in competition (Figure 3.4).

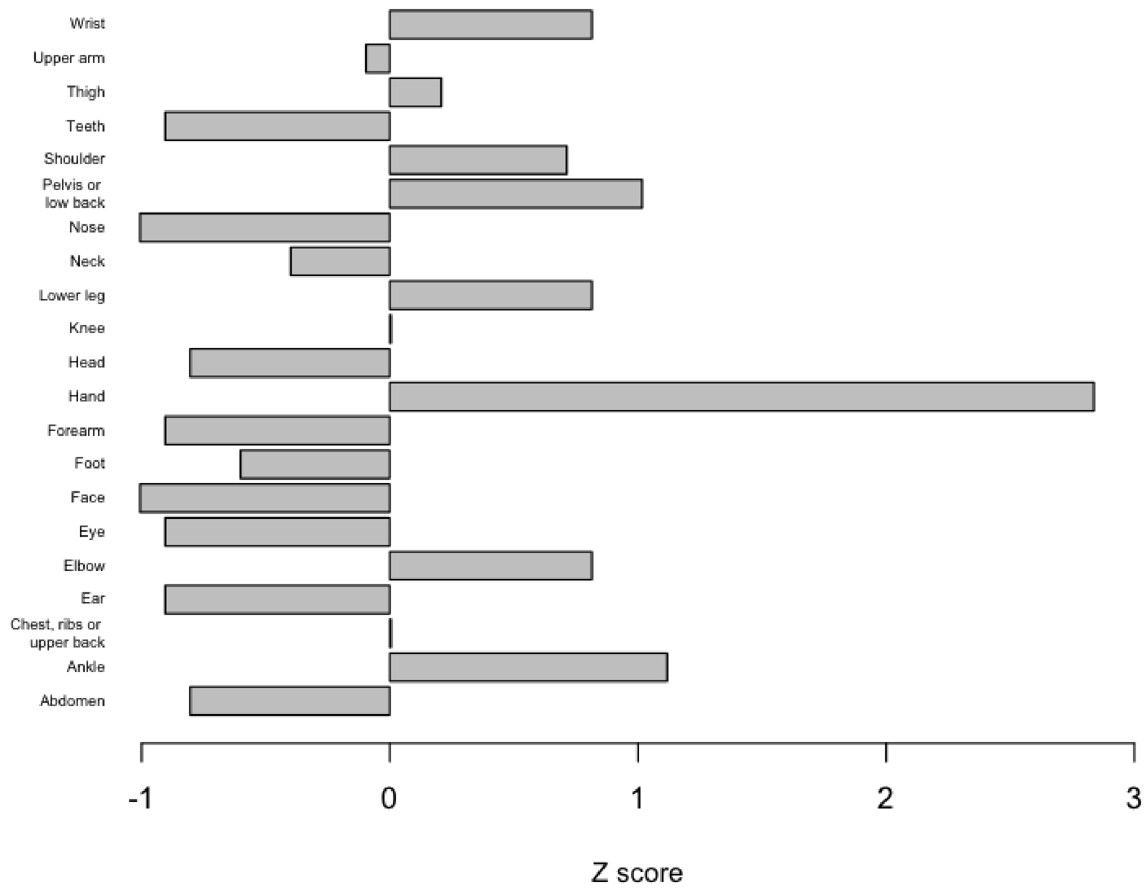

Figure 3.3 Z Scores for the Number of Injuries in Each Anatomical Location in Training in the GB Boxing Squad, 2005 – 2009

3.4.5 Injury Rate: Competition and Training

The participants engaged in a total of 6,375 minutes of competition (a mean of 96.6 minutes per subject) during the relevant period, during which 88 injuries were sustained. Thus, the injury rate was 828.2 injuries per 1,000 hours of competition time.

There were no accurate figures on attendance for individual boxers during this period. However from the detailed training notes kept by one of the coaches it is estimated there were between 900 and 1200 training hours per boxer per year, providing rates in training of between 0.7 and 1.8 injuries per 1000 hours respectively. The rate of injury in competition was at least 460 times greater than in training.

A chi square test revealed significant differences in injury rate in competition at different anatomical locations (X^2 = 122.4, p<0.05). Analysis of Z scores (Figure 3.5) showed that the injury rate in competition was significantly higher for the hand than other locations, at 301.6 injuries per 1,000 hours (Figure 3.5). There were no other significant differences between anatomical locations in respect of injury rates during competition.

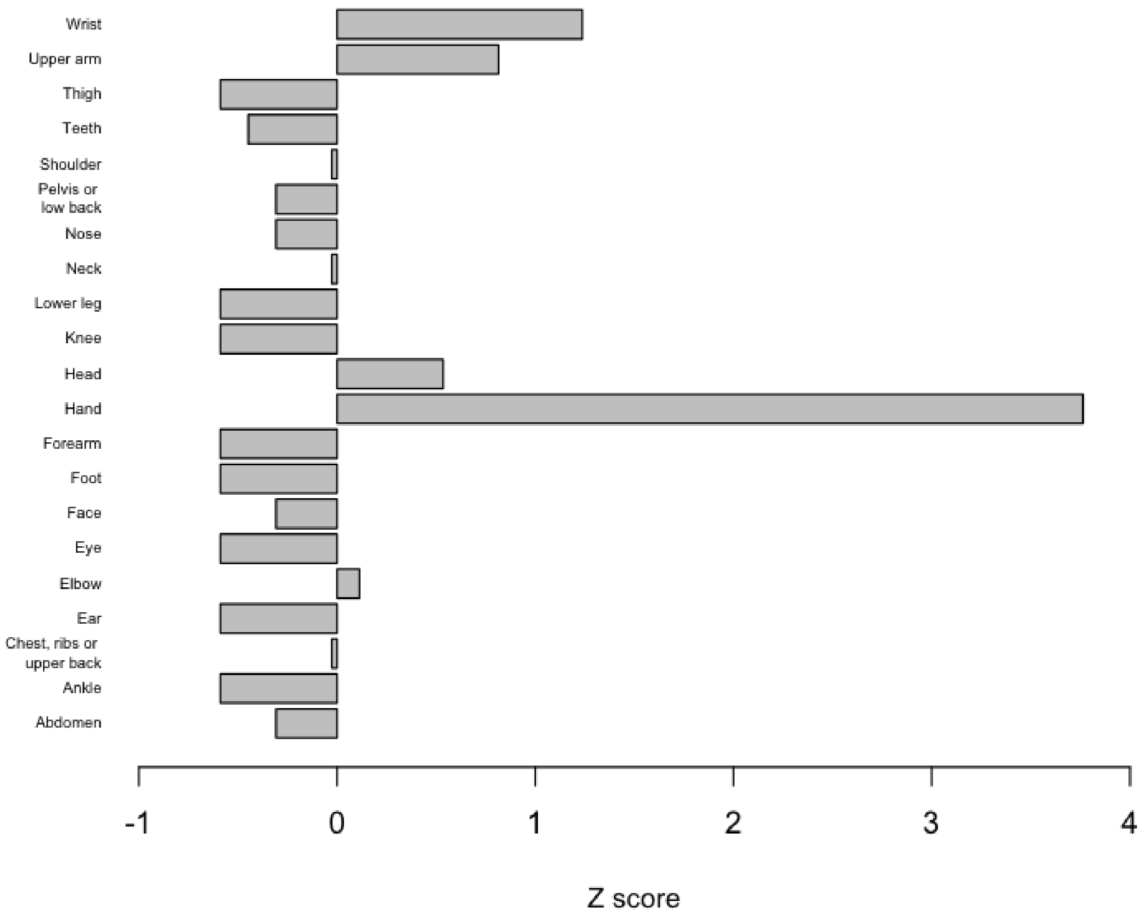

Figure 3.4 Z Scores for the Number of Injuries in Each Anatomical Location in Competition in the GB Boxing Squad, 2005 – 2009

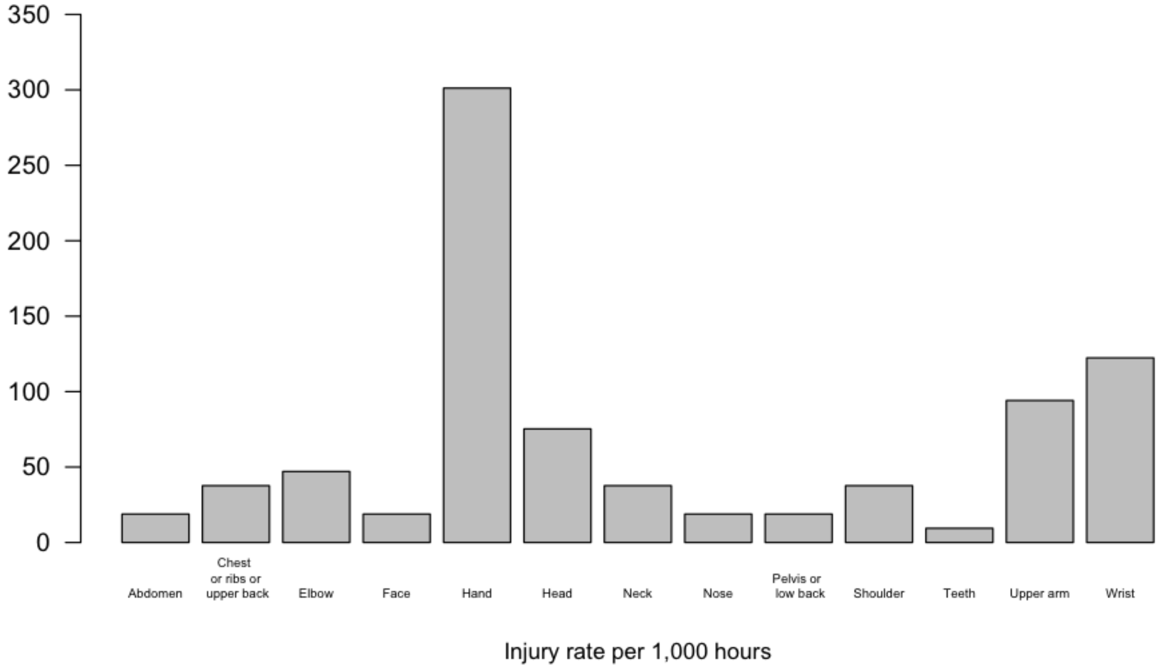

Figure 3.5 Injury Rates in Each Anatomical Location in Competition in the GB boxing Squad, 2005 – 2009

3.4.6 Injuries: Recurring Compared to Non-Recurring

The number of new and recurring injury data is shown in table 3.4. A chi square test revealed that the number of new injuries (n = 246, 82.8%) was significantly greater than the number of recurring injuries (n = 51, 17.2%) in the relevant period (X^2 = 128.0, $p<0.05$).

The mean number of recurring injuries per athlete was 1.28 injuries (range = 1 – 8 injuries). A chi square test revealed a significant difference in respect of injuries by anatomical location for both the number of recurring (X^2 = 135.5, $p<0.05$) and the number of new injuries (X^2 = 238.4, $p<0.05$). Analysis of Z scores showed that the number of hand injuries was significantly greater for both recurring (Z score = 3.6) and new injuries (Z score = 3.4). The charts below set out the Z scores for the number of recurring injuries (Figure 3.6) and new injuries (Figure 3.7) in each anatomical location.

Location	**New**	**Recurring**
Abdomen	4	0
Ankle	17	4
Chest/Ribs/Upper Back	14	0
Ear	1	0
Elbow	15	8
Eye	1	0
Face	2	0
Foot	3	1
Forearm	1	0
Hand	52	17
Head	10	0
Knee	10	0
Lower Leg	16	2
Neck	7	3
Nose	2	0
Pelvis/Low Back	18	4
Shoulder	18	3
Teeth	2	0
Thigh	9	3
Upper Arm	19	0
Wrist	25	6
Total	**246**	**51**

Table 3.4 The Location of New and Recurring Injuries

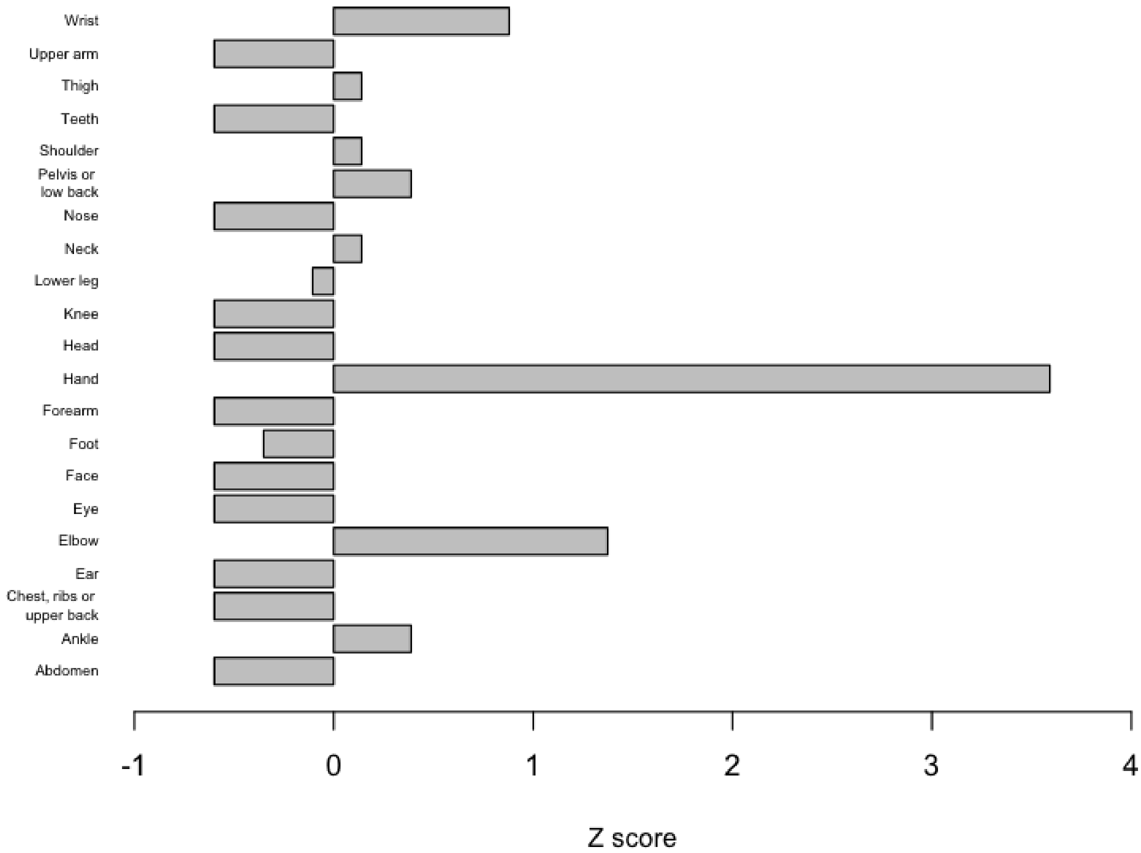

Figure 3.6 Z Scores for the Number of Recurring Injuries in Each Anatomical Location in the GB Boxing Squad, 2005 – 2009

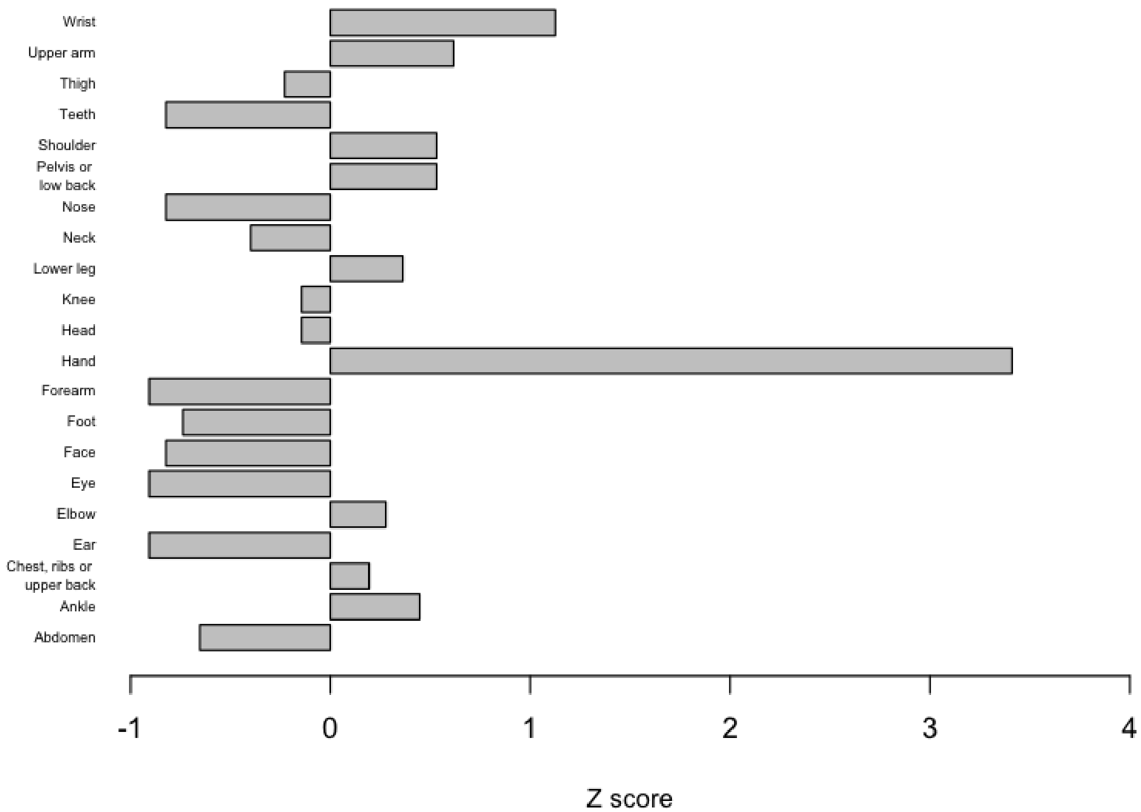

Figure 3.7 Z Scores for the Number of New Injuries in Each Anatomical Location in the GB Boxing Squad, 2005 – 2009

3.4.7 New and Recurrent Injuries by Type

The numbers of New and recurrent injuries sorted by type of injury is shown in table 3.5. A chi square test revealed a significant difference in respect of injuries by type for total ($X^2 = 323.6$, $p<0.05$), new ($X^2 = 256.7$, $p<0.05$) and recurring ($X^2 = 105.9$, $p<0.05$) injuries.

Type of Injury	**New injury**	**Recurrent Injury**	**Total**
Concussion	5	0	5
Contusion/bruise/haematoma	10	2	12
Fracture	17	0	17
Joint	13	10	23
Lesion of meniscus, cartilage or disc	6	3	9
Muscle strain/tear/rupture/cramps	58	7	65
Nerve injury	3	1	4
Other bone injuries	3	0	3
Other injuries	43	4	47
Sprain/ligament Injury	64	22	86
Tendinopathy/bursitis	18	2	20
Tendon injury/rupture	6	0	6
Grand Total	**245**	**51**	**296**

Table 3.5 Type of Injury. New and Recurrent Injury

Analysis of Z scores showed that only the number of sprain/ ligament injuries was significantly greater than the other types for total (Z score = 2.27), as well as both new (Z score = 1.99) and recurring (Z score = 2.24) injuries individually. The majority of these sprain/ligament injuries were hand or wrist injuries (69%). The chart below shows the Z scores for total injuries by type (Figure 3.8).

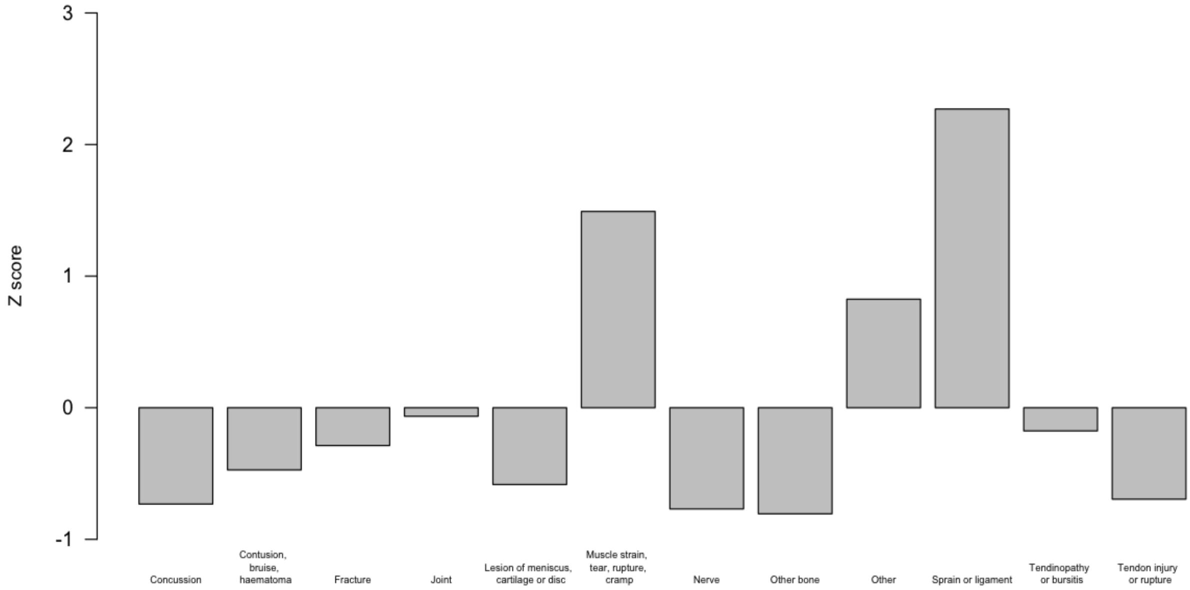

Figure 3.8 Z Scores for the Number of Injuries by Type in the GB Boxing Squad, 2005 – 2009

3.4.8 Time Lost to Injury

The total duration of time lost to injury as a result of all 296 injuries was 9,820 days and the mean duration of time lost for an injury was 33.1 days. The duration of time lost to hand and wrist injuries (45.6 days) was among the highest recorded. However, multiple regression analysis across anatomical locations revealed that only the duration of time lost to eye injury was significantly greater than that at other anatomical locations ($p<0.05$). Whether this result is meaningful is doubtful, as there was only a single eye injury recorded and this proved to be a rare genetic condition that kept the boxer on the injury list for 370 days. There were no other significant differences.

3.5 Discussion

These results clearly demonstrate that the hand is the most commonly injured location and that sprains and ligament injuries are the most common type of injury in a group of Great Britain elite level AOB boxers'. Most of the sprains and ligament injuries were to the hand and wrist. Additionally, the hand was the most commonly injured location when analysed across both training and competition and across recurrent and new injuries. Moreover, injury rate during competition was significantly greater for the hand than for other anatomical locations.

The hand has previously been identified as the location that incurs a high injury risk in amateur boxers (3) but not professional boxers. It is possible that injury risk changes because of the very large impact forces that are displayed by elite AOB and professional boxers (81-83). Such impact forces might reasonably be expected to lead to hand damage, particularly where padding is minimal (as in competition) or when performed over a repeated period of time (as in training).

It is noteworthy that the hand is the location most likely to be injured in competition, particularly as this high injury rate occurs despite only a comparatively short time throwing punches in competition compared with training. There are a number of differences between training and competition that might account for these results. Firstly, during training, it is allowable to use as much hand wrapping as desired, including tape and padding. However, during competition only a limited length of hand wrapping is allowed. During the relevant period covered by this study, hand wrapping in amateur boxing consisted of up to 2.5m of crepe bandage and no adhesive tape. Similarly, during training, heavier gloves (with more stuffing) are worn up to 18oz (510 g) in weight. In contrast, only 10oz (284 g) gloves are worn in competition. Finally, during training, punches are thrown in very controlled conditions, including hitting bags and sparring, with many punches landing at sub-maximal forces. In contrast, during competition, punches are thrown against a moving target with maximal force. It may therefore be the case that differences in respect of hand wrappings, gloves or punching conditions are responsible for the high level of hand injury in competition despite the small number of punches in comparison with training. Nevertheless, it is not clear why this group of boxers suffered so many hand injuries overall. It is my observation that amateur boxers are identified by talent agents at a young age and become full-time boxers as early as 17 years old on the GB squad. It is therefore possible that they have not had the opportunity to develop stronger wrists and hands over a longer period of training time prior to becoming full-time boxers. However, this question remains to be explored.

While the incidence of hand injury was much higher than expected based on earlier studies, the level of head and face injury was lower than the published data on professional boxing and broadly in line with data published on amateur boxing. Many previous trials have reported that the greatest proportion of injuries in professional boxing occur to the head or face. Facial injuries recorded were lower in the GB squad than those previously recorded in professional boxers. Indeed, Zazryn et al. (5) found that facial lacerations were the most commonly occurring type of injury in professional male and female boxers in Victoria, Australia accounting for 62% of all injuries recorded. Similarly, Bledsoe et al. (6) found that facial lacerations were the most commonly occurring type of injury in professional male and female boxers in the US, accounting for 51% of all injuries recorded.

Reports in AOB boxing (154) show lower numbers of facial injuries, which is almost certainly due to the wearing of head guards in amateur boxing. Previous studies have suggested that facial cuts were reduced with the introduction of head guards in 1984 (2). As shown in chapter 6 and 7 in this thesis, since head guards were removed in 2013, there has been an increase in facial cuts in competition.

The level of concussions was much lower in the GB squad than has been previously recorded in professional boxers (5) this study also reported that concussions were the second most commonly occurring type of injury in competition in professional male and female boxers in Victoria, Australia accounting for 12% of all injuries recorded. Similarly, Porter and O'Brien (14) identified that concussions were the most commonly-occurring type of in-competition injury in amateur male boxers in Ireland, accounting for 52% of all injuries recorded. In contrast, in this study, no concussions were recorded in training and only five cases were recorded in competition in the relevant period. By way of contrast, in a similar study over a four year period in elite English rugby league, 35 concussions were reported Stephenson 1996 (155). Despite the disagreement with previous studies, the low incidence of head injury in the form of concussion in this boxing cohort concurs with earlier studies that have found little evidence of chronic traumatic brain injury in AOB (156).

In addition to concussion, another common concern in professional boxing is the occurrence of eye injuries, including detached retina. In contrast to these concerns, there were no reported detached retinas in the five years of data analysed in this study. Only one eye injury was recorded, which proved to be a rare genetic condition that kept the boxer on the injury list for 370 days. The low number of head, facial, ear and eye injuries in the GB boxing cohort likely benefitted from the presence of head guards which offer a degree of protection to the face, ears and eyes. The head guards worn in training by amateur boxers are also often significantly larger and provide more facial protection than those worn in competition.

Some previous studies have noted that amateur boxers might incur overuse injuries of the lower limb as a result of the running training that they perform for conditioning (14). However, despite the boxers in this cohort running almost every day, the percentage of lower limb injuries was low. The percentage of injuries affecting the lower limb in this boxing cohort was 21.6%. In contrast, studies in elite football have reported lower limb injury rates of 75% (157) and 73.5 (158). This is possibly because the distance over which boxers run is relatively short (4 to 6 km) and does not involve quick changes in pace or direction, nor does it involve collisions with other athletes. In the gym and particularly training in the boxing ring, changes in direction are required. However, running in boxing is not done with high velocity and does not produce high shear forces similar to those which occur during the cutting manoeuvres in association football. It may also be relevant that the boxing training itself is performed on a sprung surface, which may reduce the ground reaction forces.

In this study, the overall injury rate observed in competition of 828.4 per 1,000 hours might initially appear high, particularly when compared with other sports. However, these figures are broadly in line with observations in previous investigations among AOB boxers that have used a similar prospective cohort study design. For example, Zazryn et al. reported that the overall injury rate in competition was 1,221.4 injuries per 1,000 hours (15) and they calculated that the injury rate in competition observed by Porter and O'Brien was 920.0 injuries per 1,000 hours (14).

3.6 Limitations

There were a number of limitations associated with this prospective cohort trial. Primarily, the study was limited in that it was not possible to collect reliable information about total training hours carried out during the relevant period. Nevertheless, we estimate there were between 900 and 1200 training hours per boxer per year providing rates between 0.7 and 1.8 injuries per 1000 hours, respectively. Zazryn and colleagues (15) reported that the overall injury rate in training among amateur boxers was just 0.5 injuries per 1,000 hours, which is very considerably lower than during competition and correlates with our findings.

Additionally, the current study was limited insofar as data were not collected in relation to modifiable factors that might be relevant for an understanding of why hand injuries occurred in some athletes and not others. Further work should explore whether biomechanical, anatomical, and/or other physical differences between boxers predispose certain athletes to greater risk of hand injury than others. Moreover, future investigations should explore whether differences between wrapping techniques or between lengths of wrapping used lead to a greater risk of hand injury.

In light of the rule changes in AOB since the end of this study, particularly the removal of head guards in 2013, the pattern of injuries since 2013 may well be different. In consideration of the new regulations, removing head guards from amateur boxers, and biomechanical studies showing that the glove/head guard combination reduces transmitted forces, further work is required to investigate injuries in amateur boxers today (159).

3.7 Conclusion

Hand injuries occur significantly more often than other injuries in elite level, amateur boxing. This was observed both in new and recurring injuries and across both injuries sustained in training and in competition. Injuries occurred approximately 1000 times more frequently in competition than in training. This implies that injury prevention interventions should be performed within elite level, amateur boxing squads to protect the hands and wrists of the athletes. Such interventions could include: improving the quality of the wrapping procedures in training and in competition; improving the design and quality of gloves; correcting poor technique; and implementing specific strengthening programs for the hand and wrist. As the rate of hand and wrist injuries is so high a more detailed examination of the hand injury data is required to calculate the most frequent injuries and those injuries that take the longest to return to sport. This will allow an injury prevention strategy to be focused on these areas.

4.0 Hand and Wrist Injuries in the GB Boxing Squad 2005-2012

4.1 Introduction

Chapter 3 has shown that the greatest number of injuries in the GB boxing squad were in the hand and the wrist. Hand and wrist injuries also resulted in the longest time to ‘Return to Sport’ (RTS). Injuries during both amateur and professional boxing have been reviewed in chapter 2 (sections 2.2 and 2.3). In a sport in which high forces are transmitted through the clenched fist and wrist in striking an opponent (reviewed in 2.4), injury to the hand and wrist is to be expected. The exact nature, location and description of the injuries that boxers incur to the hand is therefore of some particular interest and requires further investigation.

Eight years of prospectively gathered longitudinal hand injury data from the Great Britain (GB) boxing squad was analysed in both training and competition in order to report the exact nature, location and description of the injuries that these elite AOB boxers incurred between 2005 and 2012.

4.2 Methods

The participants included all male boxers on the GB boxing squad at any time between 1 January 2005 and 31 December 2012. The data were released by GB boxing. Ninety-eight boxers (aged 24.7 ± 3.8 years) were members of the GB boxing squad during the relevant period. There were boxers in each weight category from 48kg (light fly weight) through to over 91kg (Super Heavy Weight). The mean duration that each boxer was a member of the squad was 28.5 ± 19.8 months and the duration of membership ranged from 6 – 78 months. The total number of boxer-years in the relevant period was 232.8 years.

Data relating to the number of minutes spent competing during this period was gathered for each athlete individually from their personal boxing card which contains their full bout history. No data were recorded for the number of minutes spent in training in the same period but the time spent training was estimated from athlete training schedules provided by the boxing coaches from their own records. These records were very detailed so an accurate estimation was possible.

An injury was defined as any musculoskeletal condition that prevented the boxer from participating in either training or competition for greater than 24 hours (160). Injuries were coded using a modified Orchard Sports Injury Classification System (version 10) (152), which recorded: the anatomical location of injury; the general region affected by the injury; description of the injury; duration (number of days injured) of each injury; participation when injury occurred (training or competition); and whether the injury was new or recurrent. Recurrence of an old injury was defined as the repeated report of an injury with the same code as the previous injury this was the case even if the old injury occurred before they joined the squad however the injury was only recorded as recurrent if the original injury had been the result of boxing. Injuries were recorded prospectively and examined by a consultant hand surgeon in the more serious cases requiring surgery.

4.3 Statistical Methods

All athlete demographics (age, and weight classification), participation (training or competition), and injury information (diagnosis, location, type, duration, and whether recurring or non-recurring) was entered into an Excel spreadsheet (Microsoft, Seattle, USA). All statistical tests and analysis were performed using R (153). Chi square tests were performed to identify significant differences in respect of the numbers of injuries incurred in different athlete, participation or injury categories. Z scores were calculated to identify the individual differences. The Shapiro-Wilks test was used to assess normality of data. For normal data, one-way analysis of variance was used to assess the effects of injury type or diagnosis on the duration of injury. Where this data was not normal, the non-parametric Kruskal–Wallis test was used. Paired t-tests or Dunn's test were used for post-hoc analysis (with the Bonferroni correction for multiple comparisons) as appropriate. Significance was accepted at $p<0.05$.

4.4 Results

4.4.1 Time Spent in Competition and Training

Across all athletes, there were 218.8 hours of competition during the period of the study. The average number of minutes spent competing by each athlete in total during their membership of the squad was 133.9 ± 123.5 minutes. In contrast, the number of training hours performed by each athletes during their membership of the squad was estimated at between 900 – 1,200 hours per year, which leads to an estimate across all athletes of between 210,000 – 280,000 hours of training, and an estimated average of hours spent training by each athlete in total during their membership of the squad of between 2,100 – 2,900 hours. Consequently, each athlete spent approximately 1,000 times more hours training than competing. Estimates of training hours were based on programmed rather than actual attended training sessions during which athletes were members of the squad.

4.4.2 Overview of Hand and Wrist Injuries

During the 8-year period, there were 172 hand and wrist injuries, of which 84 occurred at the hand and 88 occurred at the wrist. Of these injuries, there were significantly more new (78%) than recurrent (22%) injuries. A similar number of hand and wrist injuries were sustained during training (44%) and during competition (56%). This lack of significant difference between injuries sustained during training and competition is remarkable given that training time is approximately 1,000 times greater than competition time.

Analysing hand and wrist injuries separately provides a similar picture. Of the 84 hand injuries, 65 (77%) were new and 19 (23%) recurrent, while out of the 88 wrist injuries, 69 (78%) were new and 19 (22%) recurrent. Of the 84 hand injuries, 40 (48%) occurred in competition and 43 (52%) in training, while out of the 88 wrist injuries, 36 (41%) occurred in competition and 52 (59%) occurred in training.

The injury rate for hand and wrist injuries combined during competition was 347 injuries per 1,000 hours (hand = 183 injuries per 1,000 hours; wrist = 165 injuries per 1,000 hours), while injury rate for hand and wrist injuries combined during training was estimated at 0.34 – 0.45 injuries per 1,000 hours (hand = 0.15 – 0.20 injuries per 1,000 hours; wrist = 0.19 – 0.25 injuries per 1,000 hours).

4.4.3 Diagnoses of Hand and Wrist Injuries

Of the 172 hand and wrist injuries that occurred, there were four injury diagnoses that together accounted for 64.9% of the injuries: finger carpometacarpal instability (21.6%), finger metacarpophalangeal joint (MCPJ) extensor expansion tendon tear/rupture and finger MCPJ and capsule sprain also known as “boxers’ knuckle”

(19.3%), thumb metacarpophalangeal joint ulnar collateral ligament first degree sprain also known as “skier's thumb” (14.6%), and wrist sprains (13.5%).

However, only the number of carpo-metacarpal instability (Z score = 2.93) diagnoses were significantly greater than the numbers of other injury diagnoses. The numbers of each injury diagnosis and their proportion of all hand and wrist injuries are shown in table 4.1.

4.4.4 Duration of Hand and Wrist injuries

During the 8-year period, the total number of days lost to training was 7,712 days, of which hand injuries accounted for 3,083 days (40%) and wrist injuries accounted for 4,622 days (60%). In Team GB boxers between 2005 and 2012 the median number of days lost for hand and wrist injuries combined was 29.5 days (Inter-Quartile Range IQR 14.0-56.0 days). The median number of days lost for hand injuries was 16.5 days (IQR 10.0-47.3 days) and the median number of days lost for wrist injuries was 31.5 days (IQR 16.5-74.0 days). The four injury diagnoses that lead to the longest total durations of time lost were carpo-metacarpal instability (2,009 days), scapholunate instability (796 days), finger metacarpophalangeal joint sprain also known as “boxers’ knuckle” (762 days), and thumb ulnar collateral ligament first degree sprain also known as “skier's thumb” (737 days). The mean and total durations of time lost to each injury by diagnosis are detailed in table 4.1.

Nature of injury	**Number**	**Proportion of hand injuries**	**Mean number of days (range)**	**Total number of days**	**Proportion of total days**
Finger distal interphalangeal joint sprain	2	1.2%	9.0	18	0.2%
Finger metacarpophalangeal joint sprain	27	15.8%	28.2	762	9.9%
Extensor expansion tendon tear/rupture	6	3.5%	109.7	658	8.5%
Proximal phalangeal fracture of fingers	3	1.8%	42.0	126	1.6%
Middle phalangeal fracture of fingers	1	0.6%	42.0	42	0.5%
Other metacarpal fracture	2	1.2%	49.5	99	1.3%
First metacarpal base fracture (Bennett's)	3	1.8%	89.3	268	3.5%
Hand abrasion	2	1.2%	4.5	9	0.0%
Hand contusion	2	1.2%	48.0	96	1.2%
Hand laceration	1	0.6%	7.0	7	0.1%
Intrinsic muscle strain	3	1.8%	20.0	60	0.8%
Other hand injury	5	2.9%	24.8	124	1.6%
Scapholunate instability	5	2.9%	172.4	862	11.2%
Triangular fibrocartilage complex tear	8	4.7%	42.5	340	4.4%
Thumb ulnar collateral ligament sprain acute (skier's thumb)	25	14.6%	30.8	752	9.8%
Carpo-metacarpal instability	37	21.6%	54.3	2,009	26.1%
Wrist capsulitis	1	0.6%	31.0	31	0.4%
Wrist contusion	3	1.8%	28.3	85	1.1%
Wrist extensor tendinopathy	3	1.8%	64.3	193	2.5%
Wrist sprain	23	13.5%	28.3	650	8.4%
Other wrist injury	10	5.8%	52.1	521	6.8%
Total	**172**	**100.0%**	**45.3 (4.5-172.4)**	**7,712**	**100.0%**

Table 4.1 Total and Mean Duration of Hand and Wrist Injuries by Diagnosis

4.5 Discussion

The hand and wrist have previously been identified as locations that have a high risk of injury in amateur but not professional boxers (6). This investigation adds to our current understanding of hand and wrist injury in elite amateur boxers by demonstrating that CMCJ instability and finger metacarpophalangeal joint extensor hood and capsule also known as “boxers’ knuckle” injuries were the most common injury diagnoses. The duration of time lost to scapholunate instability was greater than that of some other injury types. It was found that new injuries were more common than recurring injuries in this cohort of elite amateur boxers, while there was no difference between the number of injuries sustained during training or competition even though the boxers spent approximately 1,000 times more hours in training. The injury rate for combined hand and wrist injuries recorded in competition, 347 injuries per 1,000 hours, is much higher than the estimated injury rate in training <0.5 injuries per 1,000 hours. The reason for this marked difference in hand injuries in competition compared to training is not known. However in training the wraps are unrestricted, hands are protected with high density foam, material wraps and tape and larger 16oz (454g) to 18oz (510g) gloves. Furthermore, many of the punches thrown in training are not thrown at maximal effort and not all the training is punching.

In competition, only 2.5 m of crepe bandage was allowed up to 2009 when this was increased to a maximum of 4.5 m, the gloves used in competition were 10oz (284g) until 2013 when the weight was increased to 10oz (284g) up to 64kg and 12oz (340g) gloves for the weights above this. Analysis of this change in glove weight in Chapter 8 showed no significant difference in the pattern of injuries sustained. Of note, there is no limitation on material wraps and tape allowed in professional boxing, and 10oz (284g) gloves are used.

4.5.1 Carpometacarpal (CMCJ) Instability

CMCJ instability was identified as being significantly more common than other injury diagnoses in this cohort of elite amateur boxers. Such data are in keeping with previous investigations which have identified CMCJ instability as a common boxing injury. As a boxer tires, the wrist tends to collapse under load into flexion which produces strain across the dorsum of the carpometacarpal joint. As there is little to no movement at the index and middle CMCJs, and it is these joints that are loaded when a punch is thrown correctly (17), it is the ligament across the CMCJ's that becomes stretched and this results in instability of the index and middle finger CMCJ. Instability at the CMCJ leads to irritation of the joint, pain, joint laxity and eventually to peri-articular hypertrophic bone formation; this is commonly known as carpal bossing. The history examination and investigations to diagnose CMCJ instability are shown in table 4.2.

4.5.2 Boxers Knuckle

Boxers knuckle is defined as damage to the soft tissues on the extensor side of the 2nd to 5th MCPJ. Finger metacarpophalangeal sprain and extensor expansion tendon tear/rupture therefore combine to give the number of diagnosis of boxers' knuckles during the period studied. There were 33 boxers' knuckles diagnosed which accounted for 18.4% of days injured due to hand and wrist injuries, the number of days before RTS per boxers' knuckle was 44.4 days and over 1420 days lost before RTS in this cohort of elite AOB boxers.

The governing body of international boxing might consider investigating ways of increasing hand protection in competition. In professional boxing, the hand injury rate is low compared to AOB (15). In professional boxing, tape is permitted and the length of bandage is only limited by the ability to fit the wrapped fist into a glove. The history examination and investigations to diagnose CMCJ instability are shown in table 4.2.

	History	Examination	Investigation
CMC Instability	• Pain at CMC joint on impact • A feeling of instability at the CMC joint • My hand "gives way" • My hand "buckles"	• Carpal bossing at the CMC joint (Late sign) • Pain on palpation of the CMCJ • Laxity of 2nd and 3rd CMC joints on 'piano key' testing.	• Plain X-Ray – May show carpal bossing. • Further imaging often not needed if clinically unstable However • Dynamic USS – may show instability at the 2nd and 3rd MCP Joint. • MRI/MRA/3TMRI – May show the capsular (ligament defect)
Boxers Knuckle	• Pain in the knuckle on impact. • Swollen 'puffy' knuckle. • Difficulty in making a fist • Occasionally pain on extension more than flexion • Subluxing extensor tendons flexion	• Pain on palpation over either side of the extensor hood • A defect 'hole' may be felt in the indicating a potential tear of the extensor hood or capsule • Occasional volar MCPJ pain knuckle • Knuckle feels boggy. • Reduced flexion (not always especially with capsular tears) • Extensor tendon subluxation on flexion. Not always and can also be found in normal individuals.	• USS can show soft tissue oedema and suggests a structural abnormality • USS can show sagittal band tears and tendon subluxation. • MRI/MRA/3TMRI – Will show extensor hood tears +/- capsular defect Note Often USS and MRI can be difficult to interpret as the extensor hood is a very thin structure. Soft tissue oedema however is generally a reliable indirect sign for deep structural damage and often an indication to surgically explore the area.

Table 4.2 History, Examination and Investigations used to diagnose Boxers Knuckle and Carpo-metacarpal instability.

4.6 Limitations

A limitation of the investigation was inability to record accurate training hours in the relevant period. While I was able to report accurate injury rates of 347 injuries per 1,000 hours for the hand and wrist in competition, injury rates for training of <0.5 injuries per 1,000 hours remains an estimate based upon training schedules and diaries. Nevertheless, it is noteworthy that studies using reliable measurements have reported similar values for injuries overall (15). However, this is the first study to attempt to quantify and compare injury incidence rates by estimating exposure during training and competition in boxing.

The investigation was limited in that the population of the study changed during the study, with an individual boxer remaining on the squad for 28.5 ± 19.8 months. Whilst following a static population would have been preferable, natural turnover of athletes on elite amateur boxing programmes make this unfeasible. Finally, my study was limited in that certain injuries were included within “other” classifications and were not provided with definitive diagnoses for the purposes of analysis.

4.7 Conclusion

In this cohort of elite amateur boxers, CMCJ instability and boxers’ knuckle injuries were the most frequent hand and wrist injury diagnoses. The rate of injury to the hand and wrist is approximately 1,000 times greater in competition than it is in training. Individuals involved in the care of boxers should therefore be aware of the frequency of hand injuries, the duration of recovery period, and the necessary treatments for these injuries. To try to reduce these injuries in training the GB boxers use extensive hand wraps, similar to a professional boxers hand wrap, in training. A rigarous hand and wrist strengthening programme has also been instituted. Further research is required to fully understand the mechanism of injury occurring at the hand and wrist.

5.0 A Novel Method for Evaluating the Distribution of Knuckle Impact Forces in Boxing: A Feasibility Study.

5.1 Introduction

In Chapters 3 and 4 evidence is presented of the high proportion of hand injuries and the significant associated morbidity (time taken to return to sport) in elite amateur boxing.

It seems plausible that large impact forces during boxing are borne mainly by the knuckles and that these forces may be responsible for the serious hand injuries detected. Knuckle injuries have been reported in several case studies (50), and which have lead to the term “boxer’s knuckle” becoming widely used (69). Specifically, it might be that the impact force is not equally distributed across all knuckles, and that differences in the proportion of knuckle impact forces (PKIF) might lead to injury in the knuckle bearing the greatest force. Some anecdotal data do support such a concept: Hame reports that, of 27 boxers knuckle repairs, 20 were in the middle finger (50) usually the most prominent knuckle in a clenched fist. However, direct data are lacking, perhaps in large part because there is no simple method for ascertaining the PKIF at each knuckle when punching.

A solution to this problem might be the use of ‘pressure film’ such as Pressurex® (Bedford, U.K) is widely used in other engineering applications these can be seen at http://www.fujifilm.com/products/prescale/prescalefilm/#features, this technology has been used on at least on occasion in a biological application to measure to pressure between a prosthesis and a limb stump. (161), Pressurex® is a thin film (0.1016 mm – 0.2032 mm) which can reveal the distribution and magnitude of pressure and load between any two surfaces which come into contact. Pressure film has been validated for use in impact (162). Ogawa measured impact pressure applied to the pressure film using a split Hopkinson pressure bar apparatus. This allows the pressure applied to the film to be measured accurately the pressure film was able to measure the pressure for various pressures (within the range of the pressure film). The results were reproducible ±10% or less (measured by densitometer at 23°C, 65% Relative Humidity) (163)

This study sought to assess the validity and reliability of a novel pressure film technology, and to develop a method of quantifying the PKIF at each knuckle when punching.

5.2 Methods

A convenience sample of twelve participants from the Great Britain Boxing squad provided written informed consent to participate in this study. They had a mean age of 25.6 years (19.2 – 30.1 years), and body mass of 63kg (51-91 kg). Ethical approval for the study was granted by the Department for Health Research Ethics Approval Committee (REACH).

5.2.1 Pressure Film

Low standard two-sheet Fuji Film Pressurex® film (Bedford, U.K) was used to measure the pressure at each knuckle during each punch. It is able to bend and flex such that it can be used on curved surfaces *i.e.* the knuckles of the hand. The low standard film has a pressure range of 25 – 100 kg.cm^{-2} and is composed of an A-film and a C-film. The A-film consists of a micro-encapsulated colour-forming material. The C-film is made of a base coated with colour developing material. In order for the film to function and create a pressure map, the rough sides of the film need to be placed together. When pressure is applied the micro-capsules are broken and the colour forming material reacts with the colour-developing material to develop a pressure map. The intensity of the colour corresponds with the amount of load imparted on the film (see Figure 5.1).

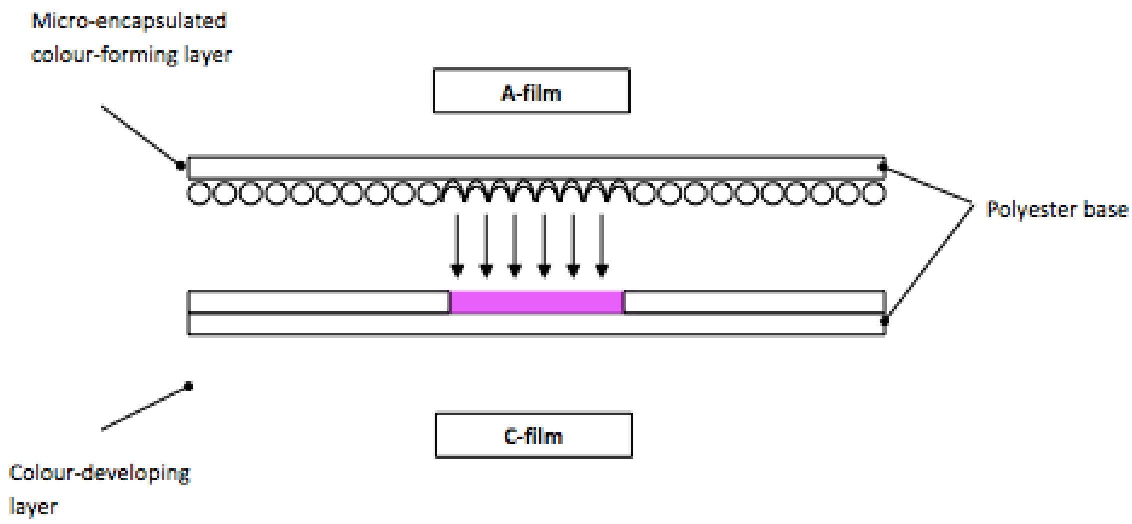

Figure 5.1 Diagram Demonstrating the Action of Pressurex® Film (adapted from FujiFilm) available:http://www.fujifilm.com/products/prescale/prescalefilm/features/

5.2.2 Wrapping and Gloving the Hands in Preparation to Punch

Participants wore two non-latex medical gloves on top of each other on the dominant hand being tested (Figure 6.2). The fingers were cut from the gloves to ensure no movement of the glove when a fist was made. The two gloves were used to hold a piece of pressure film in place, with the film sandwiched between the two gloves and the pointed end placed distally on the finger.

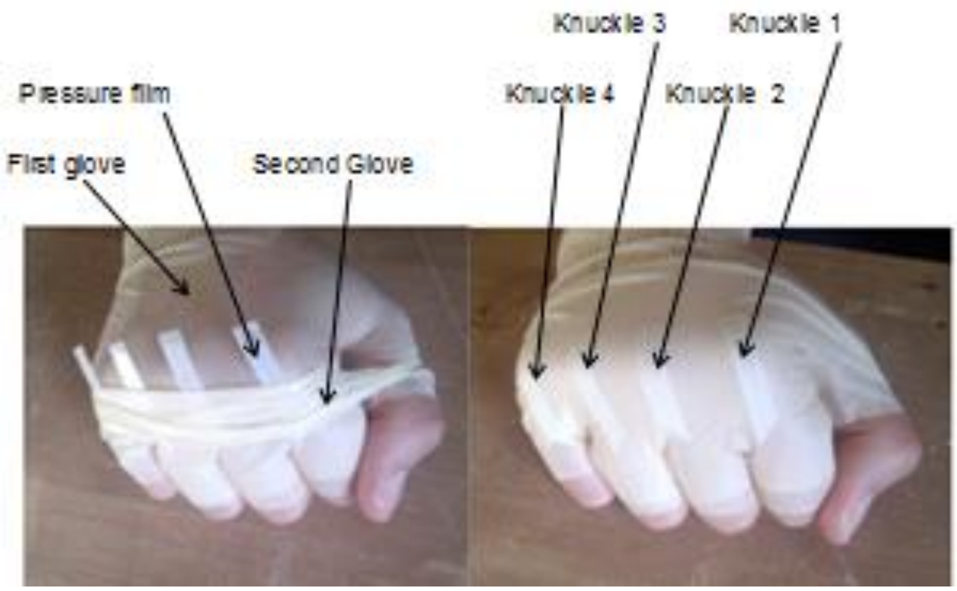

Figure 5.2 The Placement of the Pressure Film Over the Extensor Tendon at the MCP Joint, Before Wrapping of the Hands with a Competition Wrap

The two parts of the pressure film (A-film and C-film) were cut into tapered strips (Figure 5.3) 7mm wide, 38mm long on the short side, and 42mm long on the long side. The size and shape of the strip was decided on after many pilot trials with the pressure film cut to different shapes. Wrinkling or folding of the paper exposes the film, and, to avoid this, the strip had to remain narrow. This was possible as there was little lateral movement of the strip between the two surgical gloves. Making a fist produced longitudinal movement of the strip so the strip had to remain relatively long.

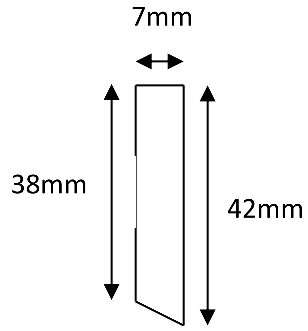

Figure 5.3 The Shape and Dimensions of the Pressure Film Utilised in Mapping the Pressures at the 2nd to 5th MCP Joints.

A tapered end was used in order to make locating the film easier. To ensure that the A-film and C-film remained together during punching trials, they were glued together at the proximal end using Loctite Super Glue (Westlake Ohio). The film was placed over each metacarpal phalangeal joint (MCP) from the second to fifth digits. The film was located with the mid-point over the MCP joint, over the extensor tendon (Figure 5.2). After the placement of the film the hands were wrapped with adiBPo3 4.5m competition black webbing (Herzogenaurach, Germany). The hands were wrapped in the same way for all punches and for all individuals (Appendix 3). After wrapping, the hand was carefully placed in a XL Everlast™ boxing glove (Moberly, USA).

Pressurex® film has an operational range for temperature and humidity (temperature: 20 - 35°C, humidity: 35 - 80%). To ensure that the environment under the wrap was within the operational range, testing with a humidity and temperature sensor was undertaken. Utilising a HP22A handheld sensor (New York. USA), with an HC2-HP28 probe (accuracy ± 0.5% humidity, 0.1°C temperature) the temperature and humidity were measured a total of 9 times, in 3 participants, immediately prior to unwrapping the hand and removing the pressure film for measurement. The probe was placed at the superior aspect of the MCP joint, adjacent to where the pressure film was located, and the hand was wrapped and gloved using the same method as with the pressure film. After a period of one minute to allow the temperature and humidity probe to equilibrate, the temperature and humidity under the wrap were recorded. Ambient temperature and humidity were also recorded at the time of each measurement.

5.2.3 Testing Whether the Act of Wrapping and Gloving Exposed the Pressure Film

It was important to investigate if wrapping the hands and putting the glove on, or the punch itself, exposed the pressure film. This was tested by wrapping and gloving the hand but not punching (no punch) and wrapping and gloving the hand and then punching (punch). The participants were either asked to punch a foam pad utilising a hook punch, that is swinging the arm which is bent at an angle of approximately 90 degrees in a horizontal arc into the pad, (punch group) or the glove was then taken off after 10 seconds (non-punch group).

The punching group was instructed to attempt to connect squarely with the centre of the pad with the knuckles, with an attempt corresponding to approximately 80% of maximal effort as judged by the boxer. This figure was believed to represent a trade-off between gathering realistic data from an elite boxer’s punch with high impact forces, while also minimising the risk of injury to the individual.

In both groups the boxing glove and the hand wrap were carefully applied and removed to avoid additional exposure to the pressure film. The pressure film was removed, and the A-film and C-film separated. The A-film was discarded and the C-film was labelled with a letter to determine which finger the piece of film was from, and with a number to denote which punch it was in a sequence of punches. The film was then catalogued for analysis. Change in image was minimised by scanning the films within 30min of exposure.

In each trial, the pressure film was scanned using an Epson B300 scanner (San Jose USA) to create digital pressure maps. Following this, the scanned film was then analysed using Fuji film mapping distribution FPD-8010E software (Bedford, U.K). This software converts the colour map into numerical load readings. An area measuring 4.5 mm x 22 mm was selected from the film corresponding to the highest area of exposure. From the Pressurex® film the maximum load at each knuckle was then calculated for each punch, for each individual.

The total load on the knuckles for each hand wrap, for each individual, was calculated by adding together the individual loads for the first to fourth knuckles of the hand. The proportion of this load accounted for by each knuckle (PKIF) was then calculated in order to determine how the load was distributed across the individual knuckles of the fist.

5.2.4 Test-re-Test Reliability

The test-re-test reliability of this method of analysing the PKIF at each knuckle was also assessed. All 12 participants performed 3 hand wraps, and performed a single punch. The dominant hand was tested in all cases.

5.2.5 Validity of the Punch Rather than the act of Wrapping the Hand exposing the Film

The validity of this method of analysing the PKIF at each knuckle was investigated by exploring whether PKIF would be similar with 'punch' and 'no punch'. Three of the participants followed the same wrapping procedure 12 times for the punch condition and 12 times for the no punch condition.

5.3 Statistical Methods

All subject (name), attempt (number), rater details (name), and PKIF at each knuckle as measured by the pressure film were entered into an Excel spreadsheet (Microsoft, Seattle, USA). The data were converted into a proportion for each knuckle for each trial and presented as a decimal fraction. All statistical tests and analysis were performed using R (153) by importing data directly from Excel. Shapiro-Wilks tests were performed to assess the normality of the data. One-way repeated measures analysis of variance (ANOVA) was used to assess for differences in the PKIF between knuckles. Adjusted paired t-tests using the Bonferroni correction were used to perform multiple comparisons between individual knuckles where an overall difference was identified. Intra-class correlation coefficients (ICC) were used to assess the test-re-test reliability of the PKIF when punching, in all twelve participants. Significance was accepted at $p < 0.05$ for all comparisons.

5.4 Results

5.4.1 Temperature and Humidity

Ambient humidity and temperature at the time of recording were 51.5% and 19.9°C, respectively. The recorded readings were as follows: Mean temperature 30.5°C ± 1.1 degrees C (range 28.7 – 32.2°C) and mean humidity 51.37% ± 3.4% (range 46.1 – 54.9%). The pressure film utilised is valid in the following ranges 20-35°C (higher for brief exposure (162)) and 35-80% humidity. Even accounting for the accuracy of the probe (±0.5% humidity, 0.1°C temperature), the environment under the wrapped and gloved hand was inside the effective range of the pressure film.

5.4.2 Validation that the Wrapping and Gloving was Not Exposing the Film

PKIF at each knuckle was assessed in 3 participants, after punching and also after putting on the boxing glove but not punching (for 12 occasions each). This showed that the act of wrapping the hands and putting the gloves on, taking the gloves off and un-wrapping the hands did expose the film.However paired t-tests revealed that there was a significant difference ($p \leq 0.05$) between the mean impact force recorded by the pressure film for all 3 participants during the punch condition (352.1 SD ± 158.2N) and the mean impact force recorded by the pressure film for the non-punch condition was (121.0 SD± 80.0N).

5.4.3 Validity of the Consistency of the PKIF – Between Knuckles and Within Subjects

In the 3 participants that had each punched on 12 separate occasions, one-way ANOVA revealed that there were significant differences in the PKIF between the knuckles ($p<0.05$). Post-hoc testing using paired t-tests found significant differences ($p<0.05$) between all of the knuckles except between knuckles 1 and 4. Visual inspection of the box plots of mean proportional knuckle impact forces for the punches performed by each subject revealed a distinct pattern for each individual. Figures 5.4 – 5.6 below show the mean proportion of impact forces for each subject across knuckles 1 – 4.

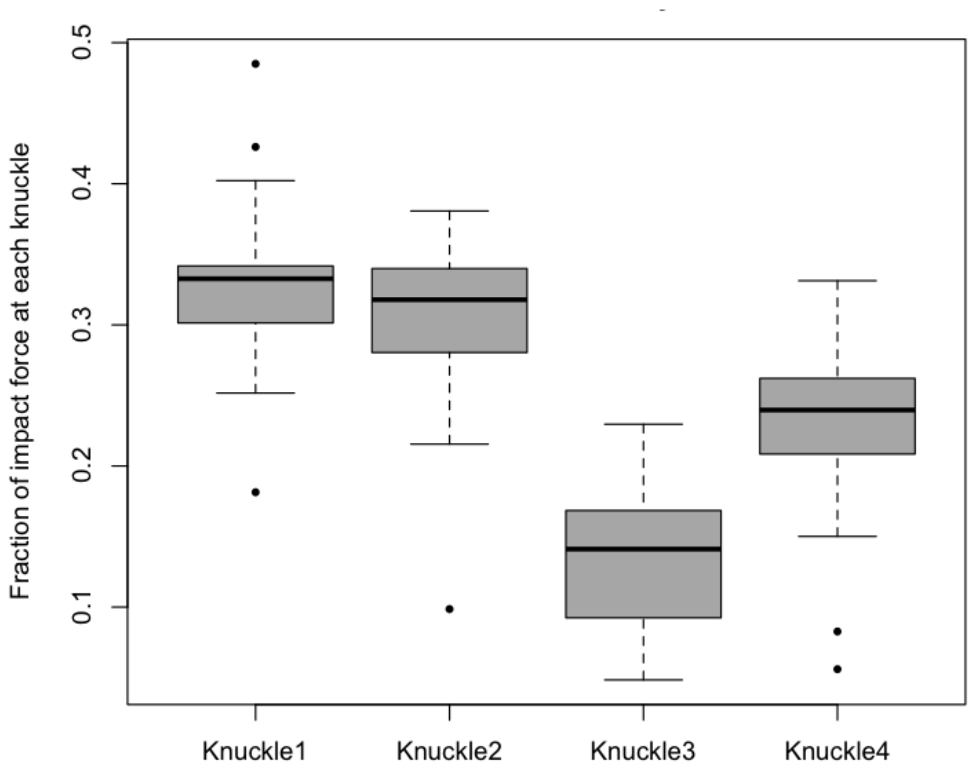

Figure 5.4 Proportion of Punching Impact Force at Each Knuckle in Participant 1

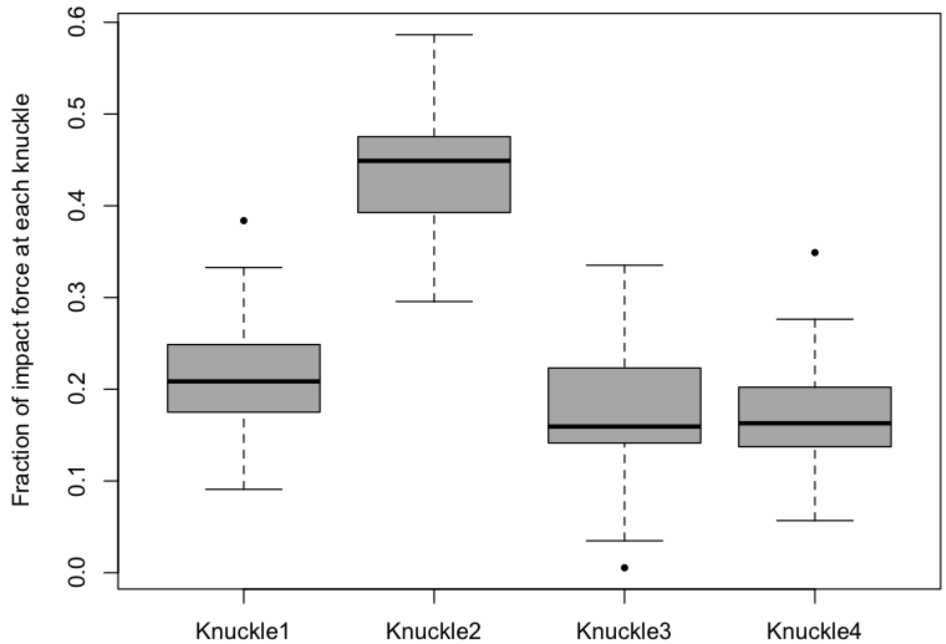

Figure 5.5 Proportion of Punching Impact Force at Each Knuckle in Participant 2

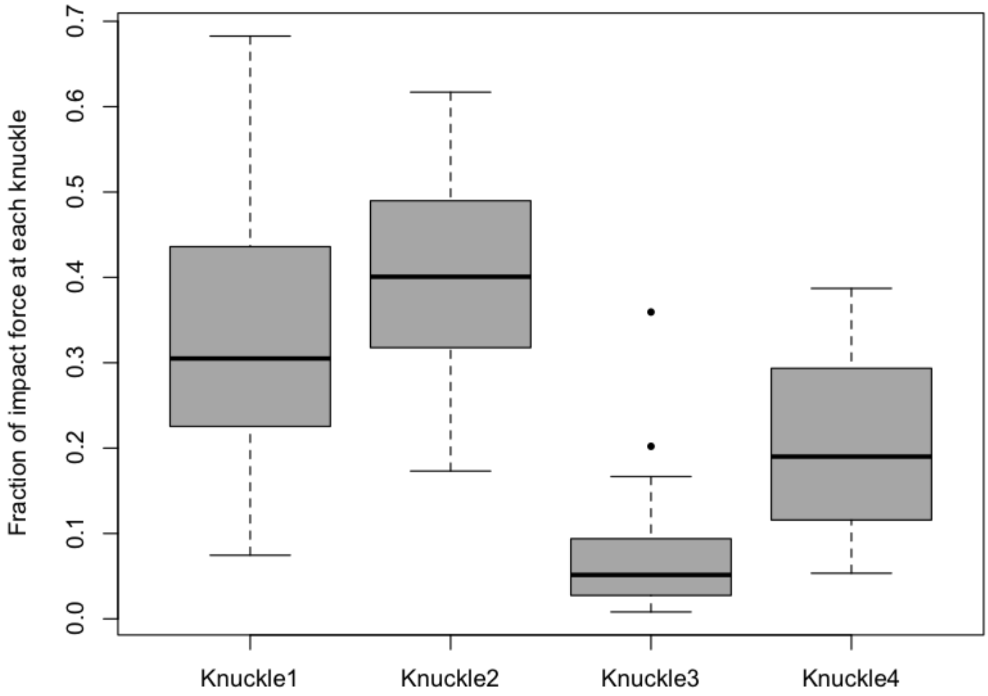

Figure 5.6 Proportion of Punching Impact Force at Each Knuckle in Participant 3

When examining the force generated by a punch at each individual knuckle, the second knuckle accounted for the largest proportion of overall force (0.38 ± 0.08 N), followed by the second (0.25 ± 0.08 N), fourth (0.23 ± 0.07 N) and third (0.14 ± 0.08 N).

After putting on and removing the wraps and gloves but not punching, the film was exposed, there were significant differences in the PKIF between the knuckles ($p < 0.05$). Post-hoc testing using paired t-tests with Bonferroni correction found significant differences between all knuckles ($p < 0.05$). The first knuckle accounted for the largest proportion of overall pressure (0.44 ± 0.17 N), followed by the second (0.31 ± 0.17 N), fourth (0.17 ± 0.14 N) and third (0.09 ± 0.08 N). This pattern of the PKIF was different from the one observed after punching, indicating that punching likely altered the pattern of the PKIF recorded by the pressure film.

5.4.4 Reliability

In this part of the experiment all 12 participants performed three independent punches. Test-re-test reliability of the PKIF at each knuckle is expressed with reference to the ICC and associated confidence intervals (CI) presented in Table 5.1. Although three out of the four ICC tests did not reach significance, test-re-test reliability was found to be poor for knuckle four, with an ICC = 0.38 ($p < 0.05$). This indicates that substantial variability in the PKIF displayed at each knuckle is caused by differences between punches performed by the same participant.

Knuckle	ICC	Significance	95% CI
1	0.067	p = 0.33	-0.21 < ICC < 0.49
2	0.078	p = 0.31	-0.21 < ICC < 0.50
3	0.29	p = 0.051	-0.052 < ICC < 0.67
4	0.38	p = 0.017	0.027 < ICC < 0.73

Table 5.1 Intra-Class Correlation Coefficients (ICC)

5.4.4.1 Descriptive Statistics

One-way ANOVA across all 12 subjects (for 3 punches each) revealed that there were significant differences in PKIF between knuckles. Post-hoc testing using paired t-tests with Bonferroni correction found significant differences between knuckle 3 and knuckles 1, 2 and 4, as well as between knuckles 2 and 4. Knuckle 2 accounted for the largest decimal fraction of the total impact force (0.34 ± 0.10 N), followed by the first (0.28 ± 0.10 N), fourth (0.24 ± 0.09 N) and third (0.15 ± 0.07 N), as shown in Figure 5.7.

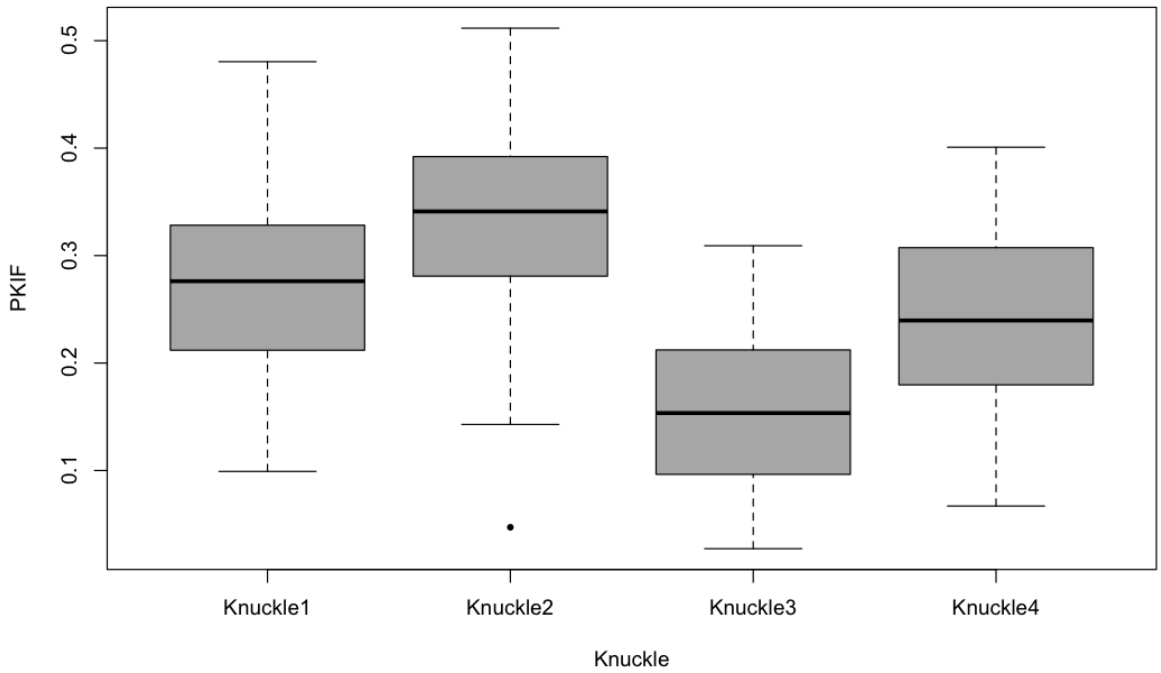

Figure 5.7 PKIF Across All Subjects and All Punches

5.5 Discussion

This study has shown that the temperature and humidity at the knuckle in a wrapped and gloved hand is within the prescribed limits for validated use of the pressure film tested. The results of this study demonstrate that the act of putting on and removing the hand wraps and the glove does not expose the pressure film more than the act of putting on and removing the hand wraps and the glove and then throwing a punch

This unique method of using pressure film does differentiate between the PKIF displayed during punching and no punching but displays very poor test-re-test reliability, since substantial variability in the PKIF displayed at each knuckle is caused by differences between punches performed by the same subject. In the subjects where 12 punches were tested the results became more reliable but there were still outliers. In this convenience sample, the PKIF observed at each knuckle was greatest in the order: second > first > fourth > third.

Subject to further investigation and achievement of superior test-re-test reliability under more controlled conditions, this method may prove useful for exploring the mechanisms of hand injury in boxing. For example, if the PKIF at each knuckle is found to differ between individuals, certain patterns of the PKIF could be predictive of hand injury risk, either because they are associated with a particular hand anatomy or because they reflect punching technique.

Identifying which knuckles are subject to the greatest PKIF in a particular athlete may prove to predict which knuckle is most likely to be damaged, should a hand injury be sustained. Furthermore, if future research finds that the PKIF is associated with increased injury risk, this technique could prove useful for devising individually tailored injury prevention strategies, such as hand wrapping techniques that place more padding over the knuckle(s) that is most at risk. This is based on the working hypothesis that, a more even distribution of forces is less likely to expose and therefore cause injury to a single anatomical structure. While this approach may help with injuries caused by punching multiple times, the technique can only measure changes in a single punch.

Currently, the risk factors for hand injury in boxing are unclear. Hand injury risk in boxing could feasibly be affected by a multitude of different factors including the magnitude of the punching impact forces, the distribution of these impact forces across the individual knuckles, or by the technique used during punching. Which of these factors is the most important, whether they interact with one another, and whether other factors are relevant, is unknown, as no previous trials have assessed the association between any of these individual factors and hand injury in boxers, either retrospectively or prospectively.

Previous studies have reported that the magnitude of impact forces can differentiate between boxers of elite, intermediate and novice groups (81) and between elite, national level and intermediate level boxers (82), respectively. Boxers of higher levels (e.g. elite national squad) consistently display greater impact forces during punching than boxers of lower levels (81). However, such studies have primarily been concerned with the effect on the head following punching, for example by determining the risk of head injury associated with the acceleration resulting from a punching impact (84). Since impact forces differ markedly between boxers of different levels, inferences might be drawn from studies that have compared overall injury rate during competition (when boxing wraps are at their thinnest and hand injury risk is greatest) (62) in amateur boxers. It might be expected that elite and professional boxers, fighting in competition, might incur more hand injuries than less-skilled athletes boxing in competition.

Although no previous studies have assessed the distribution of impact forces during punching, several previous trials have measured centres of pressure during walking. In this respect, it is interesting to note that differences in the distribution of pressure on the underside of the foot during walking have been observed when walking barefoot compared to walking in shoes (164). Grundy et al. reported that when walking barefoot there was a clear pattern for the centres of pressure to track a straight line down the middle of the foot before curving inwards to the big toe. On the other hand, when wearing shoes, the line ran straight down the whole foot without curving toward the big toe (164). Thus, it seems that the use of a covering over the foot affects the distribution of pressure during impact loading. Whether the hand wrappings used during boxing similarly affect the proportion of impact forces at each knuckle, however, is unclear.

Historically, in amateur boxing competition, only a limited length of hand wraps has been allowed (up to 2.5 m of crepe bandage). In training, longer wraps, foam padding and tape are used to protect the hands more thoroughly. It may therefore be the case that differences in respect of hand wrappings alter the distribution of impact forces during punching. If this is the case, this could be a mechanism by which a larger proportion of hand injuries are observed during competition when wrappings are far less substantial than those used in training (Chapter 4)

The effect of punching technique on hand injury risk has not been directly assessed however, Davis and colleagues (165) reported differences in techniques used for punching between winners and losers during boxing competition. They noted that winners displayed a greater number of lead hand combinations in round 1, a greater number of body-head, double-punch, and four or more punch combinations in rounds 1 and 3, a greater number of triple-punch combinations in rounds 1 and 2, and a greater number of total combinations and block and counterpunch combinations over all 3 rounds, compared with those that lost bouts. The same authors drew the conclusion that winners achieve their greater scores by means of throwing punches in combinations. Whether these differences have any influence on injury risk, however, is unclear. Bledsoe et al. (6) reported that the risk of all injury for losers was nearly twice the risk for the winners in a sample of male and female professional boxers in the US. This may suggest that some aspect of technique that differs between winners and losers during the dynamics of a single fight influences the risk of injury. Whether hand injury in particular was affected by winning or losing in this trial, however, was unclear.

5.6 Limitations

The study was limited primarily in that no external measurement of total punching impact forces was measured. Thus, while the pressure film has been used by other researchers to calculate impact forces on other parts of the human body (161), the absolute force applied by the hand and detected by the pressure film, was not quantified. Additionally, there are several factors that may have influenced the results that were not controlled.

Firstly, it is unclear to what extent the proportion of impact forces at each knuckle might be affected by the external punch force. It may be the case that greater overall impact forces are associated with a certain pattern in the PKIF, perhaps as a result of a particular punching technique (e.g. absorption by other anatomical structures) or because of greater deformation of the glove or of the target.

Secondly, no attempt to control for boxers of different abilities was performed and it is possible that more experienced boxers might display a different pattern in the PKIF compared to inexperienced boxers.

Thirdly, no measurement of knuckle anatomy was performed and therefore it is unclear whether the specific profile of knuckle loads is related to any particular anatomical features.

Fourthly, no assessment of punching kinematics was carried out and technique was not controlled, thus making it hard to assess whether punching technique is of any importance in affecting the pattern in the PKIF.

Finally, it is important to note that it still remains unclear whether there is any prospective or retrospective association between PKIF experienced at any given knuckle and increased risk of injury at that knuckle.

5.7 Conclusion

In conclusion, this feasibility study demonstrated that pressure film inserted into boxing gloves can be used to analyse the pattern of the PKIF during punching. However, test-re-test reliability of the technique is poor and would need to be improved to be of any practical utility. Further work should investigate whether there are ways of standardising punches in order to improve test-re-test reliability. Standardising the punch would reduce the variability of the punch and allow the consistency of force to be measured so changes made could be measured more sensitively as the punch variability is reduced. The relationship between PKIF and specific knuckle injury should be prospectively examined.

6.0 The Change in the Pattern of Stoppages in Amateur Boxing with and without Headguards. A Cross-Sectional Observational Study and a Case Study. Derived from AIBA Injury Data.

6.1 Introduction

Concerns within the American Medical Association regarding the potential for brain damage to boxers (166) led to the mandatory requirement to wear a head guard at the 1984 Los Angeles Olympic Games. When this decision was made, there was no evidence that head guards would reduce the risk of head injury to the boxers. Furthermore, no studies had examined optimal head guard design. Following the introduction of head guards and in the subsequent years from 1984 to 2013 no research was undertaken to determine if head guards reduced head injuries. Indeed, the role of helmets and headgear in preventing concussion in many other sports remains unclear (96).

On the 1st of January 2013, and despite an absence of research evidence supporting a rule change, the International Governing body of AOB, AIBA, removed head guards from Olympic Boxers. A recent review (2) that examined the changes in boxing rules and the relationship with patterns of injury, found that when head guards were introduced, counterintuitively, the number of stoppages due to head blows increased. However, other rule changes occurred at the same time, making causal attribution hard to prove (see Chapter 2.10).

In 2010, a new form of boxing was introduced for amateur boxers, World Series Boxing (WSB). In this form of boxing, franchises from different parts of the world compete against each other in a league system. The bouts are 5 rounds of 3 minutes each and are fought without vests or head guards using the same pool of boxers, referees and judges that are used in AOB. This gave an opportunity to compare boxing with and without head guards within the same pool of boxers and with the same referees and judges.

Accordingly, a cross-sectional observational study was conducted using data from the first three years of WSB (no head guards), and compared the incidence of stoppages due to blows to the head with data from AOB bouts (head guards) over the same period. A case study was also conducted using data from the 2009 and

2011 AOB World Championships (with head guards) and 2013 AOB World Championships (without head guards).

6.2 Methods

6.2.1 Cross-Sectional Observational Study

This is a cross-sectional observational study looking at major tournaments sanctioned by AIBA, the international governing body of AOB and WSB, over the period 2010-2012. During this period, all WSB bouts were fought without head guards; the AOB competitions were fought with head guards (Table 7.1). Information about the result of the bout and any injuries sustained by the boxers was recorded by ringside physicians who work in both AOB and WSB. The results were recorded onto standardized injury forms. The data were correlated by the lead doctor at each competition, the results were then sent to the chief medical officer at AIBA. The referees, judges and boxers also participated in both codes. Stoppages were included only if the blows were to the head, stoppages due to body blows were excluded. AIBA has always used "stoppages due to head blows" as a proxy for concussion. Every boxer stopped for head blows was examined by a physician, restricted from boxing for minimum of 30 days up to a maximum of one year. If there is any error in this proxy, it should equalize across both cohorts, as the athletes, physicians, and officials were from the same group.

6.2.2 Case Study

The last 3 World Championships from AOB. During the first two World Championships (2009 Milan and 2011 Baku) the boxers wore head guards, but for the most recent World Championship (2013 Almaty) head guards were not worn. As this was the same form of boxing (AOB) and many of the referees were the same, it was as close to comparable cohorts with and without head guards as was achievable.

The number of stoppages due to blows to the head, and cuts, from the last three senior men World Championships was recorded. The results were recorded onto standardized injury forms. The data were correlated by the lead doctor at each competition, the results were then sent to the chief medical officer at AIBA.

6.3 Statistics

Confidence intervals of the risk ratio (RR) of the number of injuries between two groups were calculated by a simple Poisson model, assuming constant hazard per group. Risk ratios are presented with 95% confidence intervals. Two-tailed P values ≤0.05 were regarded as significant.

6.4 Results

6.4.1 Cross-Sectional Observational Study

6.4.1.1 Demographics

All the boxers were male. In WSB there were five weights: Bantam (50-54Kg), Light (57-61Kg), Middle (63-73Kg), Light Heavy (80-85Kg), Heavy (over 91Kg). In AOB in 2009 there were 11 weights 48Kg, 51Kg, 54Kg, 57Kg, 60Kg, 64Kg, 69Kg, 75Kg, 81Kg, 91 Kg and Over 91Kg. In 2010 the number of weight classes in AOB was reduced to 10 from 11. The new weight classes were 49Kg, 52Kg, 56Kg, 60Kg, 64Kg, 69Kg, 75Kg, 81Kg, 91Kg and Over 91Kg.
In WSB 2010-2011 Season 1 there were 12 teams in 3 pools, 30 bouts each team. In the WSB 2011-2012 Season 2 There were 12 teams in 2 pools, 25 bouts each team.

In WSB 381 boxers took part in the competition, the average age was 24.2 years, minimum 19.1 years, maximum 34.6 years (standard deviation 3.1 years).
In AOB 930 boxers took part in the competition average age 23.2 years, minimum 17 years, maximum 34.2 years (standard deviation 3.8 years).

A total of 28,802 rounds of boxing were examined. The number of rounds boxed in AOB with a head guard was 14,880. The number of rounds boxed in WSB during the same period (2010-2012) without a head guard was 13,922. The relative risk (RR) of stoppage due to blows to the head and the RR of cuts with the head guards and without the head guards
from AOB and WSB over the period 2010-2012 are presented in Table 6.1.

	Head guard	No Head guard	P value
Stoppages due to blows to the head:	43	23	
Cuts:	45	223	
Stoppages per 1000 minutes:	0.96	0.55	
Cuts per 1000 minutes:	1.0	5.3	
Relative risk of stoppage:	1.75	0.57	<0.03
Relative risk of cuts:	0.19	5.30	<0.0001

Table 6.1 Comparison of a Similar (WSB no head guards, AOB head guards) Boxing Population Over the Same Three Year Period Both With and Without Head Guards

The data indicates a 43% lower risk of stoppages (RR=0.57) and 430% higher risk of cuts (RR 5.3).

6.4.2 Case Study

6.4.2.1 Demographics

All the boxers were male.

2011 & 2009 World Championships: 612 boxers, average age 23.7 years, minimum 17 years maximum 33.7 years, standard deviation 3.2 years

2013 World Championships: 448 boxers average age 23.8 years minimum 18.8 years, maximum 35 years, standard deviation 3.2 years.

Results from the last three senior men AOB World Championships are presented in Table 6.2. The results show a decrease in stoppages and a significant increase in cuts when the head guards were removed.

The data indicate a 45% lower risk of stoppages (RR=0.36) $p < 0.2$ and 783% higher risk of cuts (RR=8.96) $p < 0.0001$ when boxing without the head guard.

	2009 & 2011 Head Guard	2013 No Head guard	P value
Stoppages due to blows to the head:	14	2	
Cuts:	12	43	
Stoppages per 1000 minutes:	0.7	0.25	
Cuts per 1000 minutes:	0.6	5.3	
Relative risk of stoppage:	2.78	0.36	<0.02
Relative risk of cuts:	0.11	8.96	<0.0001

Table 6.2 The Last Three World Championships 2009 and 2011 with Head Guards 2013 Without Head Guards. Showing the relative risk of stoppage, and the relative risk of cuts, with and without head guards. Significance was set at $p<0.05$.

6.5 Discussion

Historically it has been suggested that the introduction of head guards in 1984 may have increased the number of stoppages due to head blows in boxing (2). However, other rule changes introduced around this time may have confounded this attribution. Head guards have never been used in WSB and their use was stopped in AOB in 2013. Studies have shown that the presence of the head guard reduces the force transmitted to the head (167). Counterintuitively, in the Cross-sectional Observational Study comparing WSB with AOB bouts occurring in the same years, there were fewer stoppages due to head blows in WSB compared to AOB (no head guards vs head guards respectively, $p<0.03$).

The case study comparing AOB world championships from years when the head guard was worn (2009 & 2011) to when head guards were removed

(2013) showed no difference in the number of stoppages ($p < 0.02$). However, the number of stoppages was very small and, as such, the study may well have been underpowered to detect an effect.

A significant increase in cuts with the removal of head guards was observed (an increase of 430% - 783% for Cross-sectional Observational Study and the Case study respectively; $p < 0.0001$ in both cases). This is a greater increase than would be expected from the historic data which showed a 50% decrease in cuts when head guards were introduced. (2).

6.6 Limitations

Limitations to this study include the observational cross design with a larger pool of AOB boxers compared with the WSB. The AOB boxers compete for three rounds of three minutes whilst the WSB boxers compete for five rounds of three minutes each.

6.7 Conclusion

The Cross-sectional Observational Study shows that removing head guards from amateur boxers appears to reduce the rate of stoppages due to blows to the head. In contrast, the incidence of facial cuts significantly increases in both studies in the boxers without head guards.

7.0 Differences in Observed Signs of Concussion With and Without Head Guards: Efficacy of a New Video Analysis Tool.

7.1 Introduction

Safety during boxing and the incidence of concussion specifically, have become a topical issue (168). Currently, stoppages due to blows to the head are being used as a surrogate diagnosis for concussion. However, stoppage may not be a sensitive marker of concussion. In a recent study, 10.6% of Amateur Olympic Boxing (AOB) boxers had concussion at the end of a bout which had been undetected during the bout by the referee or ringside doctor (138). Concussion was diagnosed if a boxer failed to reach their base line score using a computerised cognitive assessment tool (CCAT, Axon Sports). When re-tested 24 hours later, 1.3% still had changes consistent with concussion. Furthermore, the low number of stoppages due to head blows in amateur boxing may increase the risk of a type 2 error when assessing the potential role of head guards.

Video analysis provides a rich source of information on sporting injuries sustained in the field of play. To date, video analysis has largely been used in epidemiological studies to examine the circumstances surrounding the injury and to investigate possible underlying risk factors. In the concussion literature, video analysis has largely been used to investigate the biomechanics, mechanism of injury and situational factors surrounding the injury (169-175). In Australian football, a clinical and video review of impact seizures was published in 2000 (176). There have been no other studies to date on the use of video analysis in the recognition of other clinical manifestations of concussion. In the clinical setting however, video review has become an integral component in concussion recognition and assessment protocols in a range of professional sports such as American football, Ice Hockey, Rugby Union and Australian football. The video helps the clinician identify the mechanism of injury, estimate the forces involved and potentially detect observable clinical features consistent with a diagnosis of concussion, such as brief staggers or disequilibrium, tonic posturing, impact seizures, blank or vacant stare, etc.

On the 1st of January 2013, as well as head guards being removed, boxers over 64Kg wore heavier gloves (rising from 10oz (254g) to 12oz (340g)). This provided an opportunity to assess the efficacy of head guards for concussion prevention, but a more valid and reliable clinical tool would be required for assessing the incidence and severity of clinical concussion. Video analysis of bouts at the 2011 and 2013 World championships was used, looking for observable signs of concussion (OSC) from blows to the head, as a more sensitive measure of head trauma than counting the number of stoppages due to head blows. The aim of the study was to determine whether removal of head guards and/or an increase in glove weight had contributed to the apparent reduction in head trauma.

7.2 Methods

Data were collected from the senior men's World Amateur Boxing Championships from 2011 and 2013. The 2011 World Championships were the last to use head guards and 2013 was the first World Championships that head guards were not used.

Broadcast footage of all bouts from the 2011 and 2013 World Championships were analysed. Each video was reviewed for OSC, which may or may not have been detected at the time of the bout by the referee or ringside physician. The metrics used (Table 7.1) were based on work undertaken in other sports. The incidence of cuts was also examined, although it was not possible to determine the severity of the cut in terms of depth and length from the broadcast footage.

	Yes	**No**
Loss of Responsiveness	Lying on canvas, does not appear to react or reply to others around him (including, opponents, umpires, or medical staff)	Reacts or replies appropriately. Video shows no clear view of boxer on the canvas.
Impact seizure	Tonic posturing: abnormal sustained muscle contraction (usually involving one or both arms) so that the limb is held stiff despite the influence of gravity or the position of the boxer. Clonic movements:involuntary repetitive contraction and relaxation of muscles, which appears as a jerking movement or "shaking" of the arms, legs or body.	No clear evidence of tonic posturing or clonic movements. Video shows no clear view of boxer on ground.
Slow to get up	Remains on the canvas or on all fours after the count of 5 from the referee.	Return to upright position and responds to referee within the count of 5. Video shows no clear view of player on ground.
Motor incoordination	Appears "clumsy". They may be unsteady on their feet, walk in a staggered fashion or look like they have "rubbery legs";	Able to stand/walk/run in usual fashion. Video shows no clear view of player.
Rag Doll Appearance	The loss of muscular control (i.e. appears "floppy") where by the boxer does not use any protective manoeuvres as they fall to the ground (e.g. does not put out arm to protect self).	Any motor response from player in process of falling. The boxer's arms are being held, so that they are unable to move to protect themselves. Video shows no clear view of player falling.
Rough	The Boxer has sustained an 8 count or punch that has dazed him or shows signs of pain but doesn't exhibit any other head trauma response.	The boxer isn't affected by a sustained attack or heavy punch; their movement appears to be normal and fluid. Facial expressions are normal

Blank / Vacant Look	Boxer demonstrates no facial expression or emotion in response to the environment.	Any facial expressions. Video does not show clear view of face.
Cut or Bleed's locations include: Orbital Ridge Below Eyebrow Eye Lids Medial to Eye Below Eye Nose Mouth and Lips Head Other Un-Defined	Any facial laceration, facial bleeding, epistaxis/nose bleed or apparent eye injury.	No visual signs of facial injury. Video shows no clear view of player's face.

Table 7.1 Metrics used in Video Analysis for Concussion and Cuts.

7.3 Video Analysis

Phase 1

Recorded incidents were coded, using SportsCode Elite Review v10 (Warriewood, NSW Australia), by a team of six analysts composed of the following: (1) Principal Investigator (PI) the author; (2) Head Analyst who was an experienced performance analyst having worked for 8 years in boxing; (3) Lead Analyst who ran data management and assisted with training using the video coding program (SportsCode); and (4) two analysts who were postgraduate students in sport science, both of whom had previous experience of boxing or other combat sports.

The initial analysis was conducted by the two analysts after being trained in the use of the video coding program and instructed in the signs to look for on video review (see Table 7.1). Both analysts independently coded all bouts. They were allowed to watch the bout as many times as required and in slow motion if required (Figure 7.1).

The PI and Head Analyst then reviewed the results of the initial analysis. In cases where there was no uniform agreement between the two analysts, the Head analyst made a decision about the presence or absence of concussion, based on the video evidence. Intra-rater agreement was assessed by the Head Analyst revieweing the results of the initial analysis a second time, 1 week later, in 8 bouts and both results were compared. If there was a discrepancy in an incident between the first and second output, the head analyst would ask the lead analyst to review and agree on a single coding output (Figure 7.1).

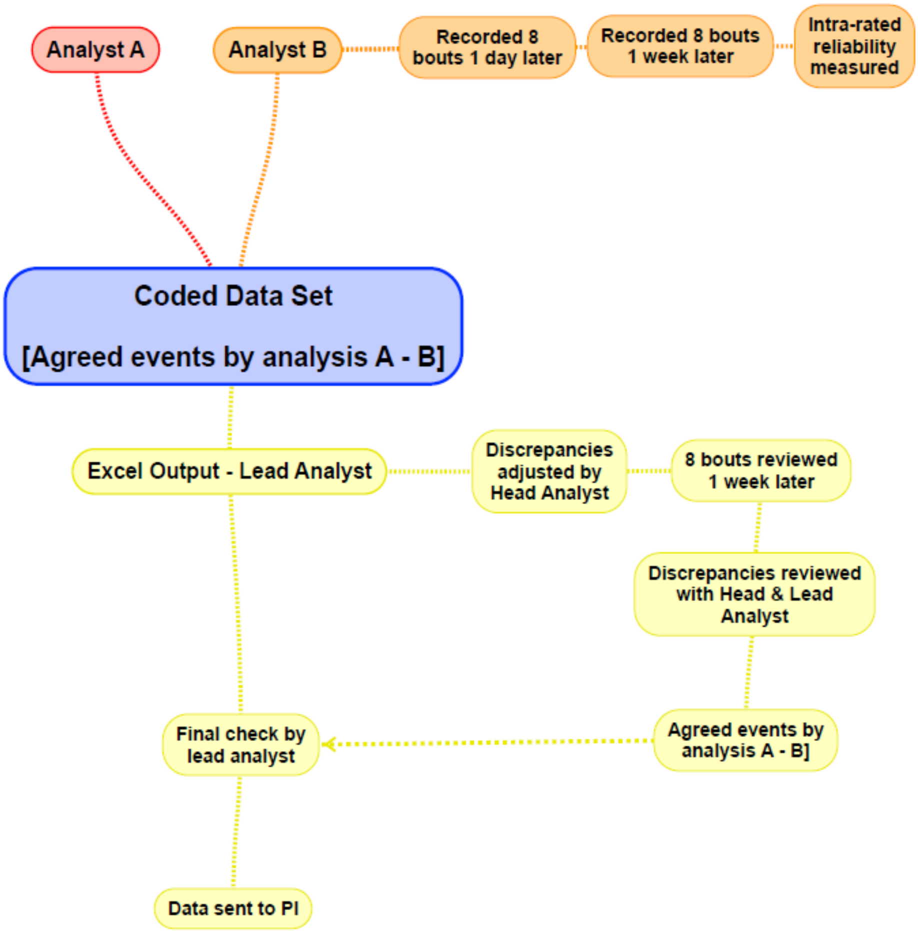

Figure 7.1 Initial Analysis Workflow.

Phase 2

Following Phase 1, a phase 2 analysis was undertaken (Figure 7.2).

The objective of the phase 2 analysis was to:

1. Identify the location on the head where the punch landed causing OSC
2. Ascertain if the punch hit the protective head guard or the area previously covered by the protective head guard.

3. Describe the head movement sustained as a result of the punch

As the footage was already coded and the incidents of OSC agreed, only two analysts were required to carry out the enhanced analysis on all of the previously observed OSC from the 2011 and 2013 World Boxing Championships. Analyst A initially coded all the enhanced analysis incidents, analyst B then reviewed analyst A's output and agreed with or amended the output in conjunction with the lead analyst (Figure 7.2).

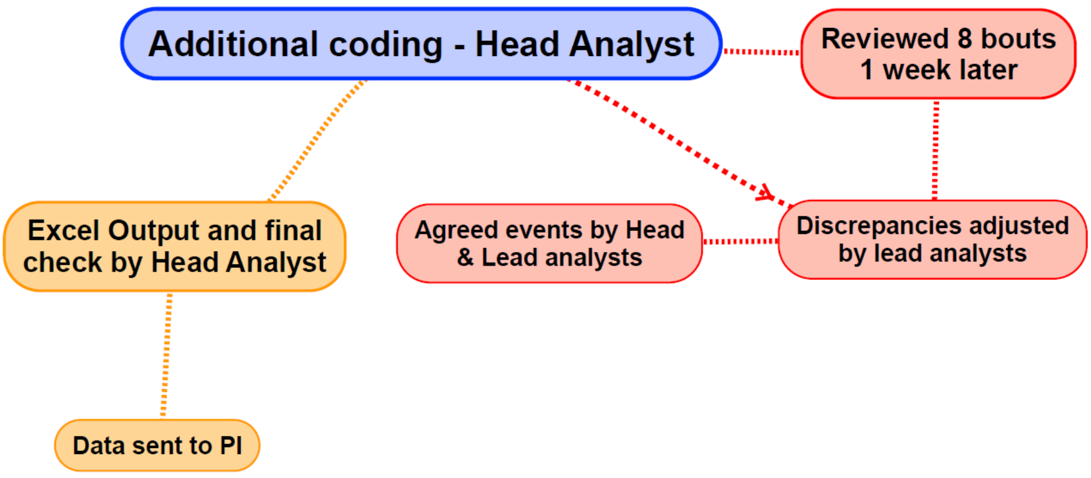

Figure 7.2 Enhanced Analysis Work Flow

The output from the phase 2 analysis coding was exported into an Excel spreadsheet and then aligned to the previously identified head trauma data.

7.3.1 Glove weight analysis

The OSC rates for the two separate weight category groups (49 kg to 64 kg and 69 kg to heavier than 91kg) were calculated for 2011 and 2013. In 2011 both groups boxed with 10oz (284g) gloves. In 2013 the 49 kg to 64 kg group boxed with 10oz (284g) gloves but the 69 kg to heavier than 91kg group boxed with 12oz (340g) gloves. The difference in the incidence of OSC between these two groups was assessed. These analyses were performed to examine the effect of the increase in glove weight in 2013 on OSC.

7.3.2 Assessment of head punch location

For the purposes of coding, five locations on the head were identified, these regions were based on the areas of the head covered by the head guard. The areas were as follows:

1) Face – From the eyebrows to below the lips and from cheekbone to cheekbone
2) Chin – From the Mentolabial Sulcus down to the laryngeal prominence and half way round the lower mandible.
3) Left/Right Side – From the end of the eyebrow round to the ear and from below the ear moving up to the point where the skull curves.
4) Top of head – From the eyebrows to the crown of the head.
5) Back of the head – from the back of the left ear to the back of the right ear

7.3.3 Determining if Punches Causing OSC Impacted the Head Guard or the Area that the Head Guard Covered After it had Been Removed

For the 2011 World Championships, whether or not the punch landed on the head guard, was observed directly from the video. For the 2013 World Championships, the analysts determined whether or not the punch would have landed on a head guard if the boxer was wearing one.

7.4 Statistics

7.4.1 Intra and Inter Rater Reliability

Fleiss' κ was run to determine the reliability of agreement between the two analysts with respect to actions reported during video footage from boxing matches.

There were 3 analyses of the same data: (1) The initial analysis; (2) The immediate analysis (24 hours later); and (3) The delayed analysis (1 week later). Fleiss' k was run to determine intra-rater agreement between the first (initial) and second analysis (immediate) and also between the first (initial) and third analysis (delayed).

In the case of intra- and inter-rater agreement Kappa values can range from -1.00 to +1.00 and a kappa value of 0.00 indicates there is no agreement between sets of scores. K-values of 0.21 to 0.40 may be regarded as representing fair agreement, whilst values of 0.41 to 0.60 may be regarded as representing moderate agreement. K-values of between 0.61 and 0.80 may be regarded as representing a substantial level of agreement (177). The p-value indicates whether the kappa value is significantly different from zero.

7.4.2 Analysis of Head Trauma and Cuts

Chi square tests were performed to identify significant differences in respect of the number of OSC and cuts incurred in 2011 and in 2013. When the assumptions for use of Chi Square were violated, differences were determined using Fisher's Exact Test. Where significant differences were found, post hoc analysis was performed, using standardised residuals in order to determine the location of any significant differences. Statistical significance was set at $p<0.05$. A standardised residual of 2.58 was used as a threshold for statistical significance at the $p<0.05$ level.

7.4.3 Glove Weight Analysis

Factorial ANOVA was performed to determine the interaction between glove weight and boxing weight category on OSC. The independent t-test with Bonferroni correction was used for the post hoc analysis of any significant findings.

7.4.4 Head Trauma in Relation to the Location of Blows and if the Blows Landed on the Head Guard or the Area Previously Covered by the Head Guard

Frequency differences between the different categories were analysed using Chi-Square. When the assumptions for use of Chi Square were violated, differences were determined using Fisher's Exact Test.

All statistical analyses were performed using SPSS version 22 (IBM Corporation, Somers, NY, USA).

7.5 Results

There were 559 bouts analysed with head guards from the world Championships of 2011 and 477 bouts without head guards analysed from the 2013 World Championships.

7.5.1 Intra-Analyst Reliability

There were two aspects to the intra-analyst reliability analyses. Firstly, there were data pertaining to immediate results when two sets of results assessed by the same analyst, on two occasions, within 24 hours of each other. Secondly, there were data pertaining to delayed reliability of the method, when the analysts analysed the footage on two occasions, 1 week apart. The results of the intra-analyst reliability of the video analysis are summarised in Table 7.2. All intra-analyst reliability results showed a substantial level of agreement.

Analyst		**Kappa Value (K)**	**p-Value**
All	Immediate result	0.86	$p<0.001$
All	Delayed result	0.78	$p<0.001$

Table 7.2 Intra-Analyst Reliability. A kappa (K) value of 0.00 indicates there is no agreement between sets of scores. K-values of between 0.61 and 0.80 may be regarded as representing a substantial level of agreement. The p-value indicates whether the kappa value is significantly different from zero. Significance was taken as $p<0.05$.

7.5.2 Inter-Analyst Reliability Results

Inter-Analyst Reliability results compared an initial analysis with the same footage being analysed again 24 hours later and the same footage again being analysed 8 weeks later. The results are reported in table 7.3.

All inter-rater reliability analyses reached statistical significance. Overall, the boxing performance analysis system appears to result in moderate to good agreement with respect to inter-rater reliability.

Analyst Assessed	Analysis	Kappa Value	P-Value
Analyst One Vs. Analyst Two	First	0.36	P<0.01
Analyst One Vs. Analyst Two	Second	0.50	P<0.001
Analyst One Vs. Analyst Two	Third	0.34	P<0.01

Table 7.3 Inter–Analyst Reliability Results. First Analysis Refers to the Initial Analysis that was Performed; Second Analysis Refers to the Analysis that was Performed 24 Hours Later; Third Analysis Refers to the Analysis that was Performed 8 Weeks Later. (Significance was set at the $p < 0.05$ level)

7.5.3 Head Trauma Difference Between 2011 and 2013 World Championships

In 2011 there were 559 bouts (5031 minutes of boxing) in 2013 there were 447 bouts (4023 minutes of boxing).

There were fewer incidents of OSC per 1000 minutes seen on the video analysis of the World Championships in 2013 (without Head guards) and more incidents of OSC recorded in 2011 (with head guards) (Table 7.4). In the video analysis there were no incidents of seizure and slow to get up was found unnecessary in this cohort as the action could be analysed using descriptions from other categories.

The data indicate that, compared to the 2011 World Championship (head guards), there was a 17% lower risk of OSC in the 2013 World Championship (no head guards). This finding is statistically significant ($p< 0.04$).

	Number of Incidents			Per 1000 minutes	
HEAD TRAUMA	2011	2013		2011	2013
BLANK/VACANT LOOK	21	37		4.2	9.2
MOTOR INCOORDINATION	131	100		26.0	24.9
RAGDOLL	7	3		1.4	0.8
LOSS OF RESPONSIVENESS	1	0		0.2	0.0
ROUGH	113	51		22.5	12.7
NON OBSERVED	19	2		3.8	0.5
TOTAL	292	193		58.1^{*}	48.1^{*}

Table 7.4 The Type of OCS Recorded in the World Championships in 2011 and 2012 Shown as the Number of Incidents and the Number of Incidents per 1,000 Minutes of Boxing. * Represents a Significant Difference ($p<0.05$)

7.5.4 Effect of glove weight on incidence of OSC

To ascertain if the change in glove weight made a difference in head trauma rates the change in OSC rates between 2011 and 2013 for each of the groups was examined. In the 49 kg to 64 kg group the change in OSC rate between 2011 and 2013 was 14.0 per 1,000 minutes of boxing. In the 69 kg to 91+ kg group the change in OSC rates between 2011 and 2013 was 14.8 per 1,000 minutes of boxing. There was no significant difference between the two groups ($p = 0.73$).

7.5.5 Findings on OSC in Relation to the Location of Blows

There were no significant differences in the location of punches to the head when using head guards (2011) and not using head guards (2013) ($p<0.05$).

7.5.6 Findings on OSC in Relation to the Blows Landed on the Head Guard (2011 World Championships) or the Head Guard Area (2013 World Championships)

In both 2011 and 2013, there was no significant difference ($p > 0.05$) between any of the video signs of head trauma and use of head guards. Of the blows causing head trauma as detected on the video analysis, 55.1% landed outside the head guard (2011) or outside the area covered by the head guard (2013) (Table 7.5)

Motor incoordination	57.5%
Rough	58.9%
Blank/Vacant	62.7%
Ragdoll	50.0%
All OSC	57.3%

Table 7.5 Percentage of Blows Causing Head Trauma That Did Not Land on the Head Guard or Area of the Head That Would Have Been Covered by the Head Guard

7.5.7 Cuts

The number of cuts increased significantly following the removal of head guards (Table 7.6). The data indicated that, compared to the 2011-championship (head guards), there was a 308% increase in cuts (RR: 4.08, 95% CI: 2.89-5.76) in the 2013 championships. This is statistically significant with $p > 0.001$ for risk of cuts.

	DATA TOTALS		Per 1000 minutes	
Position of Cut	2011	2013	2011	2013
Orbital Ridge	3	74	0.6	18.4
Below Eyebrow	0	5	0.0	1.2
Eye Lid	2	5	0.4	1.2
Medial to Eye	0	0	0.0	0.0
Below Eye	16	15	3.2	3.7
Nose	13	7	2.6	1.7
Mouth and Lips	1	2	0.2	0.5
Head	0	26	0.0	6.5
Un-defined	7	3	1.4	0.8
Total	42	137	8.3	34.1

Table 7.6 The Position and Number of Cuts Recorded in 2011 (With Head Guards) and 2013 (Without Head Guards)

7.6 Discussion

An analysis of video recordings from the 2011 (head guards) and 2013 (No head guards) men’s Senior World Championships suggests that removing the boxing head guards significantly reduces OSC in AOB boxers.

In the case of OSC although this may seem counterintuitive, these findings support previous work examining the changes in the rules of AOB boxing over a 59 year period which found that the number of stoppages due to head blows increased with the introduction of head guards into international boxing (2). This result also concurs with the findings from measuring stoppages due to blows to the head, with and without head guards (Chapter 6).

In support of the findings in this study, there is no evidence that wearing head gear reduces concussion in other sports (178). Of note, helmets only seem to be effective in preventing major injury *i.e.* skull fracture, in activities where the head contacts a hard surface *i.e.* equestrian sport (179).

As far as cuts are concerned the results of this study confirms the findings from the AIBA figures (Chapter 6) that removal of head guards has resulted in a significant increase ($p<0.001$) in the number of cuts. This finding could have been predicted as historical data has reported a reduction in stoppages due to injuries when head guards were introduced in 1984 (2).

At the same time that the head guards were removed, the size of the gloves used by the boxers above 64 kg was increased from 10oz (254g) to 12oz (340g). The results of this study demonstrate that the increase in glove size did not result in a decrease in OSC. This finding is similar to a study of amateur boxers in Denmark where the use of an unlimited length of hand bandage, voluntary use of head guards, and heavier gloves for boxers greater than 68 kg did not affect the frequency of matches being stopped due to knock outs or blows to the head (68, 180) .

In attempting to provide possible explanations for the apparent reduction in OSC when head guards are not worn, the location of blows to the head leading to OSC were assessed from video analysis. The results demonstrated that over half the blows that cause OSC did not land on the head guard when the head guards were worn, nor did they land in the region that would have been protected by the head guard, when head guards were not worn. If head guards are not reducing OSC rates, this may be because less than half of the blows causing OSC were at sites protected by head guards.
Torque is a measure of how much a force, acting on an object, will cause the object to rotate. Torque can be mathematically represented by the formula

$$T = r * F$$

where T is the Torque, r is the distance from the pivot point to the location the force is being applied (Moment arm), and F is the force applied perpendicular to the moment arm (181). Head guards increase the apparent distance from the pivot point of the head, so that a punch increases the torque (rotational force) through the head. It is also possible that the head guard affords more ‘grip’ to the boxing glove than skin or hair, resulting in more force transmission to the boxer. Further tests need to be done to confirm this.

Vision can be restricted by the head guard so it may be possible that some of the head trauma punches are not seen by the boxer (111). Counter to this, the head guard is loosely applied to the head so any increase in torque is reduced by movement of the head guard on the head. Although this has not been tested.

It has been postulated that boxers feel safer wearing head guards and therefore put themselves in greater danger. In sports such as skiing and snowboarding the wearing of helmets was found to be a significant predictor of increased risky behaviour (182). A study of cyclists in a computer simulation showed an increase in cycle speed when a helmet was worn (183). Other studies have also shown an increase in cycling speed attributed to a decrease in perceived risk when wearing a cycle helmet (184). In rugby union, players believed they could tackle harder when wearing a head protector (185).

The head guard should reduce concussion. Biomechanical studies suggested a thickness of 16 mm of polyethylene foam was optimal for force reduction in a soft head guard used in rugby union (178) this is approximately the thickness of a boxing head guard. Studies by the same author on boxing head guards showed that the head guard did reduce the force transmitted to the head (167). However like the studies presented in this chapter when this was studied in rugby union *in vivo*, no conclusive evidence was found that concussions were reduced (178).

The head guard was designed to reduce the risk of cuts in sparring by protecting the vulnerable areas around the eye socket. The padding across the forehead also protects the boxers from accidental clash of heads. If boxers are not concerned about head clashes when they are wearing head guards, as there is no risk of pain or injury, they tend to box in a head forward position. This head forward position may render the boxer more vulnerable to blows that result in the type of OSC examined in this study. The greater than expected increase in cuts may be accounted for by this head forward boxing style. This change in style is a qualitative one from the observation of experienced boxing coaches; the head forward style was not measured in the video analysis presented here.

As boxers get used to boxing without head guards the cut rate may fall. Further work is indicated to examine the impact of the removal of head guards following a period of habituation in elite amateur boxers and to ascertain the efficacy of head guard removal on boxers' health and safety.

7.7 Limitations

The quality and clarity of footage from the 2011 World Championships was inferior to that of 2013. The output from 2013 would have a slightly higher degree of accuracy due to better definition of video. Inferring whether a punch landed on a virtual head guard during the 2013 World Championships is subjective, despite having a protocol to standardise data collection. However, with a clear observation in 2011 with head guards on boxers made coding for this element far easier than for 2013. Identifying location on the head where the punch landed, in most cases, could be observed. If a film clip, either due to quality or production of the filming, inhibited clear sight of the punch landing the analysts projected where the punch would have landed.

7.8 Conclusion

These data indicate that, compared to the 2011 Senior Men's World Championship (head guards), there was a 308% higher risk of cuts, but a 17% lower risk of OSC in the 2013 Senior Men's World Championship (no head guards). Both findings are statistically significant ($p<0.05$) for risk of cuts, and for OSC. Padding the head, which was initially introduced to prevent injury to the brain, has not been shown to reduce OSC in this study. However, head guards do appear to protect boxers from cuts to the head and face.

These findings are important not only to boxing but also to other sports that may look to using head guards to reduce the risk of concussion in their sport. Sports need to consider that in using head protection they may increase the concussion rate in their sport.

8.0 General Discussion

8.1 Overview

Humans have evolved to use the clenched fist as a weapon. The ability to punch produced an evolutionary advantage associated with an enhanced fighting skill (17). The organised form of this fighting, boxing, is recorded in many different cultures across different continents as far back as recorded history (18, 19, 22). In ancient Greece where boxing was an Olympic sport (25) it had been practiced for hundreds of years. The knowledge of boxing injuries was high with accurate descriptions of boxing injuries, evidenced by depictions in life-like statues. Indeed, Hippocrates, 'the father of medicine'(29), was an expert in the subject of boxing injuries (30). Despite this high degree of injury knowledge even in ancient times the spectre of death and deformity led to boxing being banned across the Roman Empire in 500AD.

Boxing developed in England throughout the seventeenth, eighteenth and nineteenth centuries across the whole of society. Boxing as an entertainment attracted an audience from all sections of society and became the focus of gambling. With the change in the moral climate in the Victorian era bare knuckle prize fighting was forced to introduce rules to increase safety to prevent boxing being outlawed. The Queensberry rules (Appendix 2) introduced in 1865 resulted in a plethora of changes in the sport. These rules introduced boxing gloves and timed rounds and became the basis of modern professional boxing. The Queensberry rules also allowed the amateur gentleman to box competitively over three, three minute rounds. This sanitised form of boxing meant that gentlemen could enjoy the sport of boxing with little risk of permanent injury. It was this form of boxing that developed into modern Amateur Olympic Boxing (AOB).

A systematic review of the literature pertaining to injuries in boxing showed a wide variation in results. This review did suggest that hand injuries were frequent and that they occurred more frequently in amateur boxers than in professional boxers in competition.

The greatest opposition to the sport of boxing in the United Kingdom in the twentieth century has come from the British Medical Association (BMA) who, despite the lack of evidence, continually campaign for the criminalisation of boxing due to the perceived long-term damage to the brain (1). To examine the evidence for chronic brain injury in boxing this thesis presents a systematic review of the literature pertaining to CTBE in amateur boxing (Chapter 2). Findings demonstrated that much of histological data supporting the hypothesis that boxing leads to chronic brain injury was collected over a hundred years ago. At this time exposure to head blows was much greater than it is today.

These studies also have the issue of attribution; signs of traumatic brain injury are attributed to boxing when there was evidence of head injury from other sources *i.e.* boxers who had major head injuries from road traffic accidents or multiple falls due to alcoholism. Furthermore, the neuropsycometric testing used in many studies is sensitive to IQ and educational attainment leading to bias in findings which was exacerbated by the use in some studies of university students as control groups. The more recent longitudinal studies (136) show no difference in cognitive function between amateur boxers and matched controls. Indeed, the boxing cohort often achieve a higher socio-economic level than matched controls. This review demonstrated the evidence for the BMA claim that AOB causes long term brain damage to be weak (156).

8.2 General Discussion Points

8.2.1 Injuries Within the GB Boxing Squad

Despite the lack of evidence supporting chronic brain injuries, it is clear that injury rates in boxing are high. In chapter 3 injuries in the Great Britain (GB) AOB squad were reviewed. Results demonstrated that hand and wrist injuries caused the greatest burden to the boxers and the GB boxing programme in terms of prevalence and duration of time to return to sport. This study also demonstrated that the risk of injury was considerably more likely in competition than in training. There are many possible causes for this including; hitting harder in competition; hitting a moving target; and blow landing on a head or elbow, however, the most important factor is likely to be hand protection. In competition hand wrap during the period of the study was limited to 2.5 metres of crepe bandage. In training an unlimited amount of hand wrap, tape and padding is used with the only limitation being the ability of the boxer to get the wrapped fist into the glove. In professional boxing the amount of tape and hand wrap used is limited by the ability to fit into the boxing glove. Accordingly, the incidence of hand injuries in professional boxing is low compared to the amateurs. It is therefore postulated that increasing hand protection during competition would reduce the incidence of injury in AOB.

A further study was conducted examining the type of injuries occurring in the hand and the wrist (Chapter 4). This study demonstrated the commonest and most debilitating injuries were: inflammation/damage to the extensor side of the second to fifth metacarpal phalangeal joint (Boxers Knuckle); strain to the ulna collateral ligament of the thumb (Skiers' thumb); Bennett's Fracture of the thumb; and instability at the metacarpal/carpal joints. Prevention of these injuries would save the boxers time in rehabilitation and extend their careers.

The results from the hand injury data presented in this thesis have been presented to the international governing body, AIBA. The risk of hand injury is greatly increased in competition in amateur boxing in marked contrast to professional boxing where hand injuries are far less common. The main difference between amateur and professional boxing is the glove size and the amount of hand wrap allowed. Professional boxing gloves are smaller (8oz (227g)) the AOB glove weight was 10oz (284g) during the period studied. The hand wrapping in professional boxing is much more substantial compared to AOB.

It has been proposed to AIBA that both 4.5 m and 2.5 m hand wraps are available to the boxers and that each boxer is allowed to have two wraps for each hand so that the largest boxers could have two 4.5 m wraps for each hand, the smallest boxer could use one 4.5 m wrap. A midsize boxer could use a mixture of 4.5 m and 2.5 m wraps.

8.2.2 A Unique Method for Measuring Force at the Knuckle

Given the high incidence of 'Boxers Knuckle' injury a method of measuring the pressure at the knuckle would allow the effect of changes in gloves or hand wrapping to alter the distribution of pressure across the knuckles to be measured.

A method to do this was tested in Chapter 5 of this thesis. Pressure film is thin and flexible which allows it to fit against the knuckle under the hand wrap and inside the boxing glove. The concerns with this technique were that the temperature and humidity inside the glove would be outside the operating window of the film and that the act of putting on the wraps and glove may cause pressure which exposes the pressure film before the punch is thrown. This was tested and shown that the film was within its operating window for temperature and humidity and that the film exposure during the act of putting on the hand wraps and the glove was always less than the exposure of the film from punching. Furthermore, the pressure film clearly showed pressure differences between the knuckles during a punch. Due to the variability in punching technique of the boxers the test re-test reliability of the technique was poor. Whilst this study demonstrated poor reliability the findings support the potential of the technique to better understand pressure distribution during punching.

8.2.3 The Removal of Head Guards the Effect on Concussion and Cuts

In the current climate concussion in sport is under close scrutiny following a $900 million compensation pay out to American football players in the National Football League (NFL) associated with chronic traumatic encephalopathy sustained during their playing careers. Amateur Olympic Boxing has low concussion rates compared with other sports. The concussion rate per exposure (bout/event) is about one seventh of the concussion rate in rugby union (97, 101).

The international governing body of boxing (AIBA), in a rule change that seemed to be incompatible to the trend of increasing protection, removed head guards from AOB in 2013. As this rule change was controversial two experimental chapters in the present thesis were dedicated to examining the impact that this change had on concussive injury and injuries to the face (cuts). In Chapter 6 the figures provided by AIBA on the number of stoppages in boxing due to blows to the head and the number of cuts for bouts with and bouts without head guards were examined. This was performed using a cross-sectional observational study examining a total of 28802 rounds of boxing. Of these, 14880 rounds were boxed in AOB with a head guard, and 13922 rounds were boxed in WSB during the same period (2010-2012) without a head guard. A case study was also undertaken using the number of stoppages from head blows at the 2009 and 2011 World Championships where head guards were worn and in 2013 without head guards. The results from both these studies appeared to demonstrate a significant decrease in stoppages due to blows to the head after the head guards were removed.

However the number of cuts increased considerably. Indeed the number of cuts in the World Championships in 2013 following the removal of the head guards was higher than the reported number of cuts before head guards were put in place (2) in 1984.

As the incidence of stoppages due to head blows is low, a method, looking for signs of concussion in bouts that are not necessarily stopped by the referee, may give a greater number of incidents and so produce more accurate results. To achieve this, in Chapter 7 video analysis of the last World Championships with head guards (2011) and the first World Championships without head guards (2013) was carried out.

In this experimental chapter the method was shown to be valid for inter and intra-analysis reliability. Examination of the video footage for observable signs of concussion (OSC) used validated metrics from several other sports. The number of cuts was also assessed. This method identified 485 OSC, 58.1 incidents /1000 minutes of boxing with head guards and 48.1 incidents /1000 minutes after the head guards were removed. There were significantly fewer OSC in the group without head guards compared with the group with head guards ($p<0.04$). Cuts however increased by 311% in the no head guard group, a highly significant change ($p<0.001$).

Both these experimental chapters demonstrated that removing head guards from amateur boxers significantly increases the risk of cuts; however, counterintuitively the number of surrogate measures of concussions reduced with the removal of the head guard.

The findings from these experimental chapters (6 & 7) should be noted by other sports where concussion is of concern. The temptation for sports authorities to react to concerns over concussion by adding head protection, as the boxing authorities did in 1984, may in reality increase the risk of the participants suffering from a concussion. Results from this thesis indicates that governing bodies of sport should look at quantitative evidence supporting the use of head guards to ensure they provide the protection intended.

8.3 Changes Made in International Boxing as a Result of this Research

As a result of the evidence presented in chapters 7 & 8 the International Olympic Committee (IOC) decided to sanction the decision made by AIBA in 2013 to remove head guards from international boxing. As a result of the research presented in this thesis, there will be no head guards in the boxing tournament at the 2016 Olympics in Rio.

The large increase in cuts presented in this research has been presented to AIBA. In reaction to these important findings AIBA have already reacted to the increase in the number of cuts by introducing a ‘Heads Up’ (186) initiative which encourages coaches to teach the boxers not to lead with their heads and encourages referees to penalise head clashes.

8.4 Future Direction

8.4.1 Future Injury Surveillance

As a result of this research I have been directly involved with a software developer to produce an on line injury surveillance system which will be used across all AOB bouts across England. The system has been designed from the outset so that researchers will have access to the raw data. In 10 years this will give the results from over a million bouts. This data will help give accurate figures on the prevalence of injuries sustained in competition; this will inform rule changes to improve the safety of the boxers.

8.4.2 Concussion Monitoring in International Boxing

Work within boxing will continue with further video analysis of the Men’s World Championships in 2015. This will increase the data available to assess the effects of the removal of the head guards. Perhaps more importantly prospective video analysis will be collected at the Women's World Championship where head guards are still worn. After the 2016 Olympics the head guards will be removed from women's boxing. This prospective data collection will give a more accurate assessment of the effect of head guards on concussion.

Grant funding has been obtained to develop the concussion monitoring programme within international boxing. Future research will concentrate on psychometric base line assessment of all international boxers and evaluation post bout.

The research will also review other modalities of concussion assessment against this gold standard. The objective will be to have a validated, rapid assessment of a boxer post bout. The modalities will be balance assessment using a pressure plate and limb markers, abnormal eye movements, and pupillary reaction time.

Over the next 5 years this could be developed into a rapid concussion assessment system that may have applications in many other contact sports. This will result is international boxing being the only sport to have an accurate record of the incidence of concussion, as not only boxers who have a clinically detected concussion will be tested but all boxers competing.

8.5 Conclusion

The literature review (Chapter 2) shows the paucity of research into the sport of AOB, and that the literature around the dangers of chronic traumatic encephalopathy should be treated with caution. An examination of prospectively gathered injury data from the GB boxing squad (Chapter 3) showed that the GB boxing squad were prevented from participating in training and competition due to a high number of hand injuries. This study also showed that the risk of suffering a hand injury in competition was much greater than in training. A further analysis of the hand injury data (Chapter 4) demonstrated a small number of specific injuries were causing most of the morbidity, so prevention measures should be concentrated on these injuries.

To examine the knuckle a unique method of using pressure film was validated in Chapter 5, the results of which suggested it is possible that this innovation could be used in other biomechanical applications. In response to the removal of head guards in AOB, data from AIBA showing the number of stoppages due to head blows before and after the removal of head guards was examined (Chapter 6). To improve on this data video analysis of the 2011 and 2013 World Championships was conducted. Observable signs of concussion were recorded (Chapter 7). Both these experimental chapters showed that there were fewer surrogates for concussion after the head guards were removed, they also showed that there was a significant increase in cuts to the boxers.

The finding that the removal of head guards has, counterintuitively, reduced the number of concussions is important for governing bodies concerned about concussion within their sports. In 1984 when the well intentioned doctors in the American Medical Association obliged the international federation to make all boxers wear head guards (166), they increased the very outcome they were trying to prevent.

Other sporting federations should consider this finding before recommending head protection against concussion in their sports.

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Appendix 1

Broughton Rules (1743)

TO BE OBSERVED IN ALL BATTLES ON THE STAGE

I) That a square of a yard be chalked in the middle of the stage, and on every fresh set-to after a fall, or being parted from the rails, each second is to bring his man to the side of the square, and place him opposite to the other, and till they are fairly set-to at the lines, it shall not be lawful for one to strike at the other.

II) That, in order to prevent any disputes, the time a man lies after a fall, if the second does not bring his man to the side of the square, within the space of half a minute, he shall be deemed a beaten man.

III) That in every main battle, no person whatever shall be upon the stage, except the principals and their seconds, the same rule to be observed in bye-battles, except that in the latter, Mr. Broughton is allowed to be upon the stage to keep decorum, and to assist gentlemen in getting to their places, provided always he does not interfere in the battle; and whoever pretends to infringe these rules to be turned immediately out of the house. Everybody is to quit the stage as soon as the champions are stripped, before the set-to.

IV) That no champion be deemed beaten, unless he fails coming up to the line in the limited time, or that his own second declares him beaten. No second is to be allowed to ask his man's adversary any questions, or advise him to give out.

V) That in bye-battles, the winning man to have two-thirds of the money given, which shall be publicly divided upon the stage, notwithstanding any private agreements to the contrary.

VI) That to prevent disputes, in every main battle the principals shall, on coming on the stage, choose from among the gentlemen present two umpires, who shall absolutely decide all disputes that may arise about the battle; and if the two umpires cannot agree, the said umpires to choose a third, who is to determine it.

VIII) That no person is to hit his adversary when he is down, or seize him by the ham, the breeches, or any part below the waist: a man on his knees to be reckoned down.

Appendix 2

Marquis of Queensberry Rules (1865)

GOVERNING CONTESTS OF ENDURANCE

I. To be a fair stand-up boxing match, in a twenty-four foot ring, or as near that size as practicable.

II. No wrestling or hugging allowed.

III. The rounds to be of three minutes duration, and one minute's time between rounds.

IV. If either man fall through weakness or otherwise, he must get up unassisted, ten seconds to be allowed him to do so, the other man meanwhile to return to his corner, and when the fallen man is on his legs the round is to be resumed, and continued until the three minutes have expired. If one man fails to come to scratch in the ten seconds allowed, it shall be in the power of the referee to give his award in favour of the other man.

V. A man hanging on the ropes in a helpless state, with his toes off the ground, shall be considered down.

VI. No seconds or any other person to be allowed in the ring during the rounds.

VII. Should the contest be stopped by any unavoidable interference, the referee to name the time and place as soon as possible for finishing the contest; so that the match must be won and lost, unless the backers of both men agree to a draw and divide the stakes.

VIII. The gloves to be fair-sized boxing gloves of the best quality, and new.

IX. Should a glove burst, or come off, it must be replaced to the referee's satisfaction.

X. A man on one knee is considered down, and if struck is entitled to the stakes.

XI. No shoes or boots with springs allowed.

XII. The contest in all other respects to be governed by the revised rules of the London Prize Ring.

Appendix 3

Procedure for wrapping and gloving the hands 2012:

1. Ensure the hands are clean and dry and check the wrap is adequate
2. Place the loop around the thumb
3. Start by wrapping across the back of hand and do three rotations of the wrist.
4. Cross the back of the hand to wrap the knuckles starting from the fifth finger.
5. Perform three rotations of the knuckles
6. Cross the back of the hand (forming an X with the wrap)
7. Perform one complete wrap of the wrist
8. Wrap the thumb once
9. Wrap the wrist once more thus securing the thumb
10. Starting with the space between the fourth and fifth finger, wrap in between the fingers. In between wraps of the fingers wrap the wrist once
11. Wrap the wrist once
12. Wrap across the back of hand to the knuckles
13. Wrap the knuckles three times
14. Wrap back across the hand creating an X
15. Complete the wrap by wrapping the rest of the webbing around the wrist and secure the Velcro fastening.
16. Place the hand in a boxing glove and ensure the glove is secured properly.